Aspects regarding the behaviour and comfort of reusable wool protective masks in the context of the COVID 19 pandemic

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Abstract. In the current context of involvement in the fight against COVID 19 wearing protective masks are strictly necessary to limit the spread of the virus SARS-CoV2. Since the appearance of this virus, solutions have been sought to cover the needs of masks for the population and also to improve their wearing comfort compared to nonwoven fabric (TNT) masks. These masks are made of chemical fibres and it is recommended to be worn for a maximum of 4-8 hours and then they must be discarded. In this study, two types of masks from wool and silk blended knitted fabrics were manufactured and analysed. The masks were initially subjected to manual ironing sterilization and disinfection. Subsequently, several analyses were performed: specific mass, density, abrasion and pilling resistance, colourfastness to crocking, colour fastness to accelerated laundering, air permeability, bacterial filtration efficiency and breathability. The analysed masks can be washed and disinfected at home and are reusable. This aspect offers a strong sense of safety for the user, but also has beneficial effects on environmental protection. Even so, they do not correspond to bacterial filtration efficiency. Eventually, the comfort perception of about 300 volunteers was also taken into consideration.

1. Introduction
In the current context of involvement in the fight against COVID 19 wearing protective masks are strictly necessary, even imposed by the authorities, both inside and outside, to limit the spread of the virus SARS-CoV2 [1-3]. The wearing of facial masks is likely to become a habit in the future as a measure of protection against other viruses even if they are not as aggressive [4, 5]. Since the appearance of this virus, solutions have been sought to cover the needs of masks for the population and also to improve their wearing comfort compared to TNT masks (nonwoven textiles) sold through the pharmaceutical network [6-9]. The TNT masks are made of chemical fibres and it is recommended to be worn for a maximum of 4-8 hours and then they must be discarded. Also, the increase in masks utilization has led to waste accumulation and environmental issues.
For a while, another problem was the lack of medical masks and their auction at a very high price. Thus, the masks made of textile materials as personal protection have become a habit among the population. For non-medical masks realization, alternatives were searched in using various materials with filtration efficiency, breathability and low environmental impact. A series of studies were performed in which alternative materials that can capture particles and droplet were analysed [10]. Kin-Fai Ho et al. have reported that 100 % cotton towel or 70 % cotton with 30 % polyester material masks could have 40–60 % filtration capability for polydisperse sodium chloride (NaCl) aerosol particles [11].

Even if a lot of research has been done on facemasks, the number of studies on the choice of materials, especially those that have taken into account the impact on the environment due to waste and their recycling possibility is still limited. Decreasing the use of PPE and replacing materials with reusable alternatives will lead to less waste and less pollution. Moreover, the design, selection of material, number of layers and shape of the non-medical masks should be more investigated. These masks are usually done by small companies or homemade, without seeing aspects like quality, design, materials used, comfort and others.

Reusable masks or anti-virus masks could solve mask shortages or environmental issues in the future. The life of the reusable masks will be extended and anti-virus masks will annihilate the virus on the mask and will prevent a secondary infection generate by virus retention [12].

Therefore, in this study, an interdisciplinary group of researchers in collaboration with the economic environment analysed two types of self-designed facial masks made from wool and silk blended plain knitted fabric and evaluate the perception of about 300 volunteers in terms of comfort they provide.

2. Materials and methods

Two types of wool and silk blended plain knitted fabric supplied by Silvania Worsted Spinning SRL with different thicknesses and colours (grey and brown) were used to confectioned facial masks. After the industrial manufacture, the self-designed facial masks were initially subjected to manual ironing sterilization and disinfection treatment at 125 °C with steam at 110 °C using industrial ironing boards equipped with professional irons in laboratories of the Engineering Faculty at the Aurel Vlaicu University of Arad. Laboratory analyses of the masks were performed at the Research- Development- Innovation in Technical and Natural Sciences Institute from “Aurel Vlaicu” University of Arad and to Techtex SRL laboratory. Subsequently, several analyses were performed: the specific mass (grams per square meter), the density of the knitted fabrics, the abrasion and pilling resistance, colourfastness to crocking by Crockmeter Method, colour fastness to accelerated laundering, air permeability, bacterial filtration efficiency (BFE) and breathability. The BFE and breathability results were compared with those of disposable TNT masks.

2.1. GSM (grams per square meter) of knitted fabrics

Fabrics weight was measured according to ASTM D 3776 / D3776M - 09a "Standard Test Methods for Mass Per Unit Area (Weight) of Fabric" on ten circular specimens taken from different parts of the knits using the GSM cutter device. The circular samples were weighed using an analytical balance and subsequent calculation of the weight in grams per square meter was done.

2.2. The density of knitted fabrics

The number of wales and courses per unit distance for both types of knitted fabrics were determined on five samples by using a pick glass and a counting device following ASTM D 3887-96(2008) „Standard Specification for Tolerances for Knitted Fabrics”.

2.3. Abrasion and pilling resistance

The evaluation of the abrasion resistance was performed with the Martindale Abrasion and Pilling Tester - model YG401B. Two samples from each type of knitted fabrics were measured for weight
loss and colour change. The analyses were made under ASTM D4966-12- "Standard Test Method for Abrasion Resistance of Textile Fabrics (Martindale Abrasion Tester Method)".

After some preliminary analysis, the number of rubbing cycles for the two types of knitted fabrics was established. An important factor for establishing this number, along with the behaviour of the knit in the rubbing process, was the mass/m². Thus, for the grey knit with a mass of 155.50 g/m², the number of rubbing cycles was established between 1000 - 5000 rubbing cycles with the step of 1000 cycles and for the brown knit with a mass of 220.43 g/m² in the range of 10000 - 20000 rubbing cycles with the step of 5000 cycles.

The colour change evaluation was performed with Datacolor 500 colourimeter. On each sample, the measurement was done at three different points. The index used to assess colour change was the colour difference between the abraded samples and the untested control sample. Based on the colour difference, the equivalent grade of the greyscale for colour change was calculated. This evaluation was made following AATCC Evaluation Procedure 7-2009- "Instrumental Assessment of the Change in Colour of a Test Specimen".

To assess the pilling resistance of the knitted fabrics, the same standard ASTM D4966-12- "Standard Test Method for Abrasion Resistance of Textile Fabrics (Martindale Abrasion Tester Method)" was used. To give a rate, the tested samples on the Martindale device were compared with a set of five photographs 105 mm numbered 1 to 5, illustrating different degrees of pilling from “very severe pilling” to “no pilling”.

2.4. Colourfastness to Crocking: Crockmeter Method
The evaluation of colourfastness to crocking of the dyed knitted fabrics was done according to the standard AATCC Test Method 8-2007- "Colourfastness to Crocking: Crockmeter Method" on the Crock Meter Y571D. This test method is designed to determine the amount of colour transferred from the surface of coloured textiles to other surfaces as a result of rubbing with an arm that mimics the human finger. The tests were performed on both dry and wet crocking methods. The colour change of the tested samples and colour transferred to a standard white test cloth was evaluated with Datacolor 500 colourimeter according to AATCC Evaluation Procedure 7-2009- "Instrumental Assessment of the Change in Colour of a Test Specimen". Colourfastness grade was assigned based on the colour difference between specimens that had been submitted to the colourfastness tests and the colour of an identical untreated specimen.

2.5. Colourfastness to accelerated laundering
The accelerated laundering test is to evaluate the colourfastness to laundering of textiles. The evaluation of knitted fabrics samples was performed according to the AATCC Test Method 61-2009 - "Colourfastness to Laundering: Accelerated" with a Launder - Ometer, model M228AA. The use of the accelerated washing method is equivalent to five cycles of home laundering. The Datacolor500 colourimeter and the standard - AATCC Evaluation Procedure 7-2009 - "Instrumental Assessment of the Change in Colour of a Test Specimen" were used to evaluate the colour change of the samples subjected to washing.

This evaluation covers two aspects: the colour change of the material subjected to washing and the amount of colour transferred from the samples surface to other surfaces of a fabric consisting of 6 types of fibres (acetate, cotton, nylon, silk, viscose, wool), called "multifiber".

2.6. Air permeability
The air permeability assessment was performed according to ASTM D 737 - 04 - "Standard Test Method for Air Permeability of Textile Fabrics" with the Digital Air Permeability Tester, model YG461E. The measurements conditions were: pressure (P) = 100 Pa, nozzle diameter (D) = 14.5 mm, test area of the sample 20 cm². For an accurate evaluation of the material permeability, 10 measurements were made in different areas on each type of knitted fabrics.
2.7. Bacterial filtration efficiency (BFE) and breathability

The test method for bacterial filtration efficiency (BFE) was performed according to the European standard SR EN 14683 + AC: 2019, section 5.2.2. and Annex B. The method consisted of determining the aerosol penetration coefficient with particle diameter between 0.3 – 10 μm on a Mask Bacterial Filtration Efficiency Tester, model GK-1000 from Ningbo Dahe Instrument Manufacturer.

Section 5.2.2. and Annex C from the same standard was used to evaluate the face masks breathability (differential pressure). The GT-RA04 Face Mask Differential Pressure Tester was used to determine the air exchange pressure of the face masks material by measuring the differential pressure required to draw air through a measured surface area of 4.9 cm² from the mask at a constant airflow rate of 8 l/min.

3. Results and Discussion

3.1. GSM (grams per square meter) and density of the knitted fabrics

Table 1 and table 2 present the GSM values and density for both types of analysed knitted fabric and represent the average of 10 measurements. The mass/m² was an important factor for establishing the number of rubbing cycles for abrasion and pilling resistance testing.

| Table 1. GSM of the knitted fabrics. |
|--------------------------------------|
| Grey knitted fabric [g/m²] | Brown knitted fabric [g/m²] |
| 155.50 | 220.43 |

| Table 2. The density of the knitted fabrics. |
|---------------------------------------------|
| Grey knitted fabric | Brown knitted fabric |
| Wales/centimeter (wpc) | Courses/centimeter (cpc) | Wales/centimeter (wpc) | Courses/centimeter (cpc) |
| 12 | 20 | 12 | 18 |

3.2. Abrasion and pilling resistance

To evaluate the abrasion resistance, the samples were weighed before and after each step of rubbing cycles. The values for the initial mass, the final mass and calculated weigh loss are presented in table 3 and table 4.

| Table 3. The weight loss after abrasion resistance tests for grey knitted fabric. |
|------------------------------------|
| Samples | Number of rubbing cycles | Initial mass - m₁ [g] | Final mass – m₂ [g] | Weight loss [%] |
|------------------------------------|
| 1 | 1000 | 0.220 | 0.217 | 1.36 |
| | 2000 | 0.214 | 0.210 | 1.87 |
| | 3000 | 0.220 | 0.212 | 3.64 |
| | 4000 | 0.213 | 0.202 | 5.16 |
| | 5000 | 0.225 | 0.209 | 7.11 |
| 2 | 1000 | 0.211 | 0.209 | 0.95 |
| | 2000 | 0.212 | 0.205 | 3.30 |
| | 3000 | 0.228 | 0.219 | 3.95 |
| | 4000 | 0.227 | 0.215 | 5.29 |
| | 5000 | 0.215 | 0.198 | 7.91 |
Table 4. The weight loss after abrasion resistance tests for brown knitted fabric.

| Samples | Number of rubbing cycles | Initial mass - m_i [g] | Final mass – m_f [g] | Weight loss [%] |
|---------|--------------------------|------------------------|---------------------|-----------------|
| 1       | 10000                    | 0.254                  | 0.241               | 5.39            |
|         | 15000                    | 0.254                  | 0.240               | 5.51            |
|         | 20000                    | 0.254                  | 0.236               | 7.08            |
| 2       | 10000                    | 0.241                  | 0.229               | 4.98            |
|         | 15000                    | 0.241                  | 0.227               | 5.80            |
|         | 20000                    | 0.241                  | 0.225               | 6.64            |

From the values obtained for both types of knitted fabric, it can be seen that the weight loss was directly proportional to the number of rubbing cycles, being between 7 - 8 % after 5000 cycles for the grey knit and 6 - 7 % for the brown one after 20000 cycles. Also, a decrease in material thickness was found, but without any perforations.

Because after the abrasion resistance tests, the pilling phenomenon appeared on the tested side of the fabrics, it was decided that for the colour change evaluation, the samples should be measured both on the front side of the material and on the backside of the material. In figures 1 to 4 are presented the colour difference – ΔE values and the attributed colourfastness grade for the front and backside of both grey and brown knitted fabric samples subjected to abrasion resistance testing.

![Figure 1](image1.png)  
**Figure 1.** The colour difference – ΔE and colourfastness grade for the front side of grey knitted fabric.

![Figure 2](image2.png)  
**Figure 2.** The colour difference – ΔE and colourfastness grade for the backside of grey knitted fabric.

![Figure 3](image3.png)  
**Figure 3.** The colour difference – ΔE and colourfastness grade for the front side of brown knitted fabric.

![Figure 4](image4.png)  
**Figure 4.** The colour difference – ΔE and colourfastness grade for the backside of brown knitted fabric.
From the obtained values, it can be observed that for both the front and backside of the grey knitted fabric, the “endpoint” was reached at 4000 rubbing cycles when the colour change of the material was evaluated with grade ~ 3 according to greyscale. The "endpoint" for the brown knitted fabric was not reached even at 20000 rubbing cycles. According to the greyscale, the assigned grade was ~ 4.

After pilling resistance testing, the knitted fabrics were compared with a set of five photographs numbered 1 to 5, illustrating different degrees of pilling as presented in figure 5.

![Grade 5: no pilling](image1)
![Grade 4: slight pilling](image2)
![Grade 3: moderate pilling](image3)

![Grade 2: severe pilling](image4)
![Grade 1: very severe pilling](image5)

Figure 5. Photographic standards for pilling evaluation.

The appearance of both types of knitted fabric subjected to pilling resistance testing is shown in figure 6. After comparison with the photographic standards, the grey knit was marked with grade 4 and the brown knit with grade 3. As a result, the brown knitted fabric has a more pronounced tendency to form pilling compared to the grey one.

![Grey knitted fabric](image6)
![Brown knitted fabric](image7)

Figure 6. The appearance of knitted fabric samples after pilling resistance testing.

3.3. Colourfastness to Crocking: Crockmeter Method

The colourfastness to dry and wet crocking of knitted fabrics samples was evaluated by measuring the colour transferred to a white standard test cloth and by measuring the colour change of the
tested samples. Colourfastness grade was assigned based on the colour difference between specimens that had been submitted to the colourfastness tests and the colour of an identical untreated specimen.

Tables 5 and 6 present the data obtained after dry and wet crocking of the grey knitted fabric.

**Table 5. The colourfastness to dry crocking of the grey knitted fabric.**

| Samples | The colour change of the knitted fabric samples | The colour transferred to white test cloth |
|---------|-----------------------------------------------|------------------------------------------|
|         | Colour difference ΔE | Colourfastness grade | Colour difference ΔE | Colourfastness grade |
| 1       | 1.22 | 4.28 | 1.47 | 4.14 |
| 2       | 1.21 | 4.29 | 0.81 | 4.52 |

**Table 6. The colourfastness to wet crocking of the grey knitted fabric.**

| Samples | The colour change of the knitted fabric samples | The colour transferred to white test cloth |
|---------|-----------------------------------------------|------------------------------------------|
|         | Colour difference ΔE | Colourfastness grade | Colour difference ΔE | Colourfastness grade |
| 1       | 1.62 | 4.05 | 5.34 | 2.32 |
| 2       | 1.75 | 4.02 | 6.68 | 2.03 |

For the brown knitted fabric, the colour change and colourfastness values after dry and wet crocking are presented in table 7 and table 8.

**Table 7. The colourfastness to dry crocking of the brown knitted fabric.**

| Samples | The colour change of the knitted fabric samples | The colour transferred to white test cloth |
|---------|-----------------------------------------------|------------------------------------------|
|         | Colour difference ΔE | Colourfastness grade | Colour difference ΔE | Colourfastness grade |
| 1       | 0.61 | 4.64 | 0.72 | 4.58 |
| 2       | 0.78 | 4.54 | 0.79 | 4.54 |

**Table 8. The colourfastness to wet crocking of the brown knitted fabric.**

| Samples | The colour change of the knitted fabric samples | The colour transferred to white test cloth |
|---------|-----------------------------------------------|------------------------------------------|
|         | Colour difference ΔE | Colourfastness grade | Colour difference ΔE | Colourfastness grade |
| 1       | 0.46 | 4.73 | 2.79 | 3.36 |
| 2       | 0.74 | 4.56 | 6.82 | 2.00 |

The data presented, show an insignificant colour change of the grey and brown knitted fabrics samples after both dry and wet crocking tests. Thus, the grades assigned according to the greyscale were between 4.02 - 4.73.

Similar values were obtained for the amount of colour transferred to white test cloth in case of dry crocking, the assigned grades being between 4.14 - 4.58.

A different behaviour was noticed for wet crocking, where the colour transfer was more accentuated and the colourfastness grades were 2.00 - 3.36.
3.4. Colourfastness to accelerated laundering

The colour change (colour difference – ΔE) and assigned colourfastness grade of grey and brown knitted fabrics after accelerated laundering are shown in figure 7.

![Figure 7](image)

**Figure 7.** The colour difference and colourfastness grade to accelerated laundering of the grey and brown knitted fabrics.

As the data show, for both types of knitwear, there is a good colour resistance to accelerated laundering, the assigned colourfastness grades being 4.39 for grey knitted fabric and 4.58 for brown ones.

The amount of transferred colour on the "multifiber" support of knitted fabrics samples subjected to accelerated laundering is presented in figures 8 and 9. For the grey knit there was a low transfer on the acetate, nylon and viscose fibres followed by the wool and cotton. An accentuated transfer of the dye occurred on the silk fibre, the attributed colourfastness grade being 3.09.

For the brown samples, the values related to colour transfer shows better resistance to accelerated laundering, the attributed grades being over 4 for most fibres, except for the cotton fibre where the colourfastness grade was 3.75.

![Figure 8](image)

**Figure 8.** The colour difference and colourfastness grade to accelerated laundering of the grey knitted fabrics.

![Figure 9](image)

**Figure 9.** The colour difference and colourfastness grade to accelerated laundering of the brown knitted fabrics.
3.5. Air permeability

The air permeability values obtained for the ten measured areas of grey and brown knitted fabrics are presented in table 9.

| Samples | Air permeability (mm/s) | Grey knitted fabric | Brown knitted fabric |
|---------|-------------------------|---------------------|---------------------|
| 1       | 10900                   | 14300               |
| 2       | 12700                   | 12700               |
| 3       | 12100                   | 12900               |
| 4       | 13900                   | 12700               |
| 5       | 11200                   | 10400               |
| 6       | 10400                   | 10300               |
| 7       | 11000                   | 10200               |
| 8       | 10800                   | 12100               |
| 9       | 11600                   | 10400               |
| 10      | 10500                   | 10600               |

**Average values** 11510 11660

From the air permeability values presented in table 10, a certain structural non-uniformity of the tested knitted fabrics can be observed. Even if the two types of analyzed knitted fabrics have different thicknesses, the air permeability is similar. This may be due to the similar density of the knits as well as the porosity.

3.6 Bacterial filtration efficiency (BFE) and breathability

The evaluation of the results regarding BFE and breathability of the analyzed knitted fabric masks was made in comparison with the results obtained for the medical face masks. Figure 10 shows the bacterial filtration efficiency (BFE) and breathability of grey and brown knitted fabric masks compared to TNT medical face masks.

![Figure 10. The bacterial filtration efficiency (BFE) and breathability of the grey and brown knitted fabrics masks compared to TNT medical face masks.](image-url)
The results obtained for the bacterial filtration efficiency at the particle diameter of 2.5 μm show a low efficiency of both grey and brown knitted fabrics masks (~ 30 – 32 %) compared to TNT medical face masks (98 %). Instead, good breathability can be observed with low values of 1.41 -1.46 Pa/cm² for the pressure drop compared to 40 Pa/cm² for TNT masks.

3.7. The comfort perception

Conclusions on the wearing comfort of the masks were formulated on the basis of a questionnaire. The questionnaire consists of 16 questions. The questionnaire was completed by 258 respondents (148 women and 110 men) with an average age of 36.4 years. The analysis of the questionnaire shows that there have been no dimensional changes or comfort changes after wearing and washing the masks at home, for none of the two variants (90% of respondents). 75% of respondents did not feel any skin irritation when wearing masks and no special odor. Related to the comfort offered by the knitted masks in comparison with TNT masks more than 50% of respondents consider them more comfortable.

4. Conclusions

The analysed masks made of natural fibres compared to disposable ones can be washed and disinfected at home and are reusable. This aspect offers a strong sense of safety for the user, but also has beneficial effects on environmental protection. TNT masks are made of chemical fibres and it is recommended to be worn for a maximum of 4-8 hours and then they must be discarded. Of course, these natural fibre masks can be manufactured at higher costs, both in terms of raw materials and labour, than those of TNT, but through reuse, the user's financial effort is lower overall.

Despite all these benefits the knitted fabric masks do not fulfil de requirements regarding bacterial filtration efficiency according to European standard SR EN 14683 + AC: 2019 for medical masks. Eventually, the comfort perception of about 300 volunteers could also be taken into consideration.

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