Evaluating the ultraviolet protection factor (UPF) of various knit fabric structures

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Abstract. Public awareness regarding the risks of prolonged skin exposure to the sun light and more specifically to the UV spectrum part is increased during the last decades. Clothing is the most natural and suitable way of protecting the human body, thus the market interest in clothes that can offer adequate UV protection is growing continuously. Previous research works have revealed the main factors that influence the ability of fabrics to block harmful UV radiation. However, the variability of these factors and the versatility of their combined effect make UV protection factor prediction difficult and hence the design of fabrics with high performance against UV radiation becomes a complicated task. Hopefully, the most critical and predictable among all factors is the fabric structure itself. Expectedly, closer and tighter structures offer higher UV protection. Due to this fact, the majority of previous research concern woven structures which generally are less porous and offer a higher UV protection. However, the possibility to obtain knitted fabrics with adequate UV protection factor is of great interest, since knitted fabrics are more appropriate for sports as well as for casual summer fashion garments. Current literature regarding the UV protection factor of knitted fabrics is very limited and concerns mostly fabrics produced in machines of relative large gauges. In the present work the UV protection factor of various typical weft-knitted structures, produced in a flat knitting machine with 7 gauge and by using grey 100% Organic Cotton yarns, Ne 30/2, 330 TPM (twists per meter) is studied. The yarn has been selected due to the increasing market interest for Organic Cotton products.

1. Introduction

Since clothing is the most natural and convenient way of protecting the human body from external environmental factors, the market interest in clothes that can offer adequate protection against UVR is growing continuously. Depending on the radiation intensity, the penetration degree and the respective harm that the various wavelengths can cause to human skin significantly increases. Generally, skin damage risk increases exponentially as wavelength decreases, thus radiation at 280 nm is estimated to be 1000 times more damaging than radiation at 340 nm [1]. Prolonged exposure to UVA causes
ageing of the skin and some risk of skin cancer, while much shorter exposure to UVB causes erythema (skin reddening and burn) and increased risk of cancer [1,2]. The most dangerous region is UVC, which is related to extensive skin damages and extremely high risks of skin cancer. Fortunately, the earth’s stratospheric ozone layer absorbs radiation with wavelengths between 100 nm and 290 nm, therefore it blocks the UVC and some part of the UVB radiation [1-3]. Thus, protection from sunlight refers to protection mostly from the harmful UVB, but for longer exposure times also from the UVA region of the solar spectrum. In the previous years, in a wide range of UV shield products, the protection from the UVA used to be neglected, but nowadays it is considered as essential.

In order to rate the UV protection that is provided by various protection shields, like sunscreens, fabrics or colored glasses, the international scientific community has established the Ultraviolet Protection Factor (UPF), which is calculated by the following equation (1):

$$\text{UPF} = \frac{\sum_{\lambda=290}^{400} E_\lambda \cdot S_\lambda \cdot \Delta \lambda}{\sum_{\lambda=290}^{400} E_\lambda \cdot S_\lambda \cdot T_\lambda \cdot \Delta \lambda}$$

where,

$E_\lambda$ is the solar UVR spectral irradiance in W·m$^{-2}$·nm$^{-1}$
$S_\lambda$ is the relative erythemal effectiveness according to the CIE [4,5]
$\Delta \lambda$ is the wavelength interval of the measurements
$T_\lambda$ is the spectral transmittance at wavelength $\lambda$
$\lambda$ is the wavelength (in nm)

Based on their measured UPF, UV protective shields are classified into specific UPF rating categories in accordance to international standards (Table 1). The practical meaning of a UPF rate can be explained with the following example. If an unprotected normal fair skin starts exhibiting signs of erythema (reddening) after 10 minutes of continuous exposure to UV solar light, a protective shield with UPF=15 can extend this exposure time by 15 times, i.e. 150 minutes [2]. Higher UPF values above 40 (rating 40+) or 50 (rating 50+) are considered as “totally” safe “sun-blocks”.

**Table 1.** UPF rating categories according AS/NZS, ASTM and European standards [1-4,6,7]

| Protection  | AS/NZS 4399:1995 and ASTM D6603 | EN 13758-2:2003 |
|-------------|-------------------------------|-----------------|
|             | % UVB Transmittance | UPF Range | UPF Ratings | % UVB Transmittance | UPF Range | UPF Ratings |
| Excellent   | less than 2.5     | above 40  | 40, 45, 50, 50+ | less than 2.5     | above 40  | 40+         |
| Very good   | 4.1–2.6          | 25–39     | 25, 30,35     | 3.3–2.5          | 30–40     | 30          |
| Good        | 6.7–4.2          | 15–24     | 15, 20        | 5.0–3.4          | 20–29     | no value    |
where

\[ T_\lambda \] is the spectral transmittance at wavelength \( \lambda \),

\( m \) and \( k \) are the number of measurement points between 315 nm and 400 nm and between 290 nm and 315 nm respectively, i.e. depending

Previous research has revealed the main factors that influence the ability of fabrics to block harmful UV radiation. A summary of these factors can be found in the next section. However, the variability of these factors and the versatility of their combined effect makes any a priori estimation of the UV protection performance of a fabric difficult. Thus, the design and engineering of a fabric with high UV protection performance becomes a complicated task, since the only way to secure its performance is to measure the final incident UV transmittance and calculate its actual UPF. Since closer and tighter structures offer higher UV protection, the majority of previous research concern woven structures which generally are less porous and offer a higher UV protection. However, the possibility to obtain knitted fabrics with adequate UV protection factor is of great interest, since knitted fabrics are more appropriate for sports as well as for casual summer fashion garments. Current literature regarding the UV protection factor of weft-knitted fabrics is very limited and concerns only fabrics produced in machines of relative large gauges, like T-Shirts. At the same time, there is a strong market interest in fashion garments made of natural fibres, such as organic cotton, which can offer high comfort levels.

The target of the present research is to evaluate the UPF of fabrics produced in a small gauge flat knitting machine (7 gauge) by using organic cotton yarns and to define the structures which can serve as a basis for further developing and constructing heavier gauge knitwear with good UV protection capabilities.

2. Factors influencing the UPF of fabrics

2.1 Fabric structure (construction)

The fabric structure is the most critical factor in the UV protection performance of a fabric. Closer and tighter structures exhibit less open spaces between the yarns that form the fabric, thus allowing less UV radiation to be transmitted through the fabric. In this respect, the actual structural parameter that determines the UV protection performance of a fabric is the porosity or otherwise the cover factor (CF) of the fabric, which can be defined as the percentage area occupied by yarns in a given fabric area. Previous research has shown the relation between some other constructional parameters, such as the fabric weight or the fabric thickness, with the resulting UPF. For a given fabric structure, an increase in the weight per unit area or in thickness, normally decreases the fabric’s porosity and results to an increase in the UPF. However, a different lighter and thinner structure made of the same material may exhibit higher UPF, indicating that the dominant parameter in the UV protection performance is the fabric structure itself and its respective porosity. [7,11,13]

2.2 Material (fiber type)

Fiber type is the second most critical factor that determines UV protection performance of a fabric. Generally, synthetic yarns have superior UV performance than natural fibers. Fabrics made of 100% polyester yarns exhibit the highest UPF ratings and thus are widely used for technical sports garments.
However, natural fabrics due to their hydrophilic properties offer superior comfort levels. Blending of natural with synthetic fibers may lead to more comfortable garments with increased UPF ratings [11,13]

2.3 Color
The fabric color influences significantly the UPF. As a general rule, darker colors absorb more UVR resulting higher UPFs [11]. Dark colors, like black, blues, dark greens, improve significantly the fabric UPF, while light colors show little improvement when compared with the undyed. Since different dyes maintain a different absorption spectrum, the UPF improvement exhibits a large variability which depends not only on the shade but on the dye type as well [7,11,13]. A UPF increase from 12 to 34 has achieved with the use of red or blue dyes [13]. In the case of 100% polyester fabrics, which already have high UPFs, the effect of color is not significant [13]. Naturally-colored cotton that contains color pigments has also found having high UPF values (green UPF = 30 to 50+, tan UPF = 20 to 45 and brown UPF=40 to 50+) while conventional unbleached cotton has UPF = 8 [12].

2.4 Bleaching (whitening)
Bleaching of fabric reduces the UPF. Natural fibers contain substances which act as UV absorbers. With bleaching these natural UV absorbers are removed and the UPF drops. Conventional unbleached cotton has a UPF = 8 because of its content in natural pigments, pectin, and waxes, while bleached cotton exhibits UPF < 4 [12,18].

2.5 Stretch (fabric deformation)
When a fabric is stretched, structural deformation tends to move yarns apart and create more open spaces between them resulting in an increase in fabric porosity. By applying higher tensions and increasing fabric stretch, significantly larger drop in the UPF values is observed [11]. Especially weft-knit fabrics which are inherently susceptible to dimensional changes and structural deformation exhibit dramatic changes in the UPF when stretched. In order to get the maximum UV protection from a knitwear it should be worn in a loose and un-stretched fit.

2.6 Wetness (water absorption)
The influence of wetness on the UPF depends primarily upon the fabric’s material, namely the type of the containing fibers. Cotton fabrics provide significantly less UVR protection in their wet state than in their dry state. However, study in linen, viscose and polyester fabrics has shown that UPF significantly increases with wetting [11]. It is worth mentioning that the same study gives important evidences that, in almost all fabric cases saturation with tap water or salt water have the same effect on the UPF, and the moisture of the skin which is in contact with the fabric does not alter the fabric UPF value [11]. Alteration of the UPF due to water absorption can be explained partially due to the swell or shrinkage effect on particular fibers, which results in change of the fabric’s porosity, and partially due to the alteration of the optical properties of the fabric, i.e. scattering effect can be reduced, leading to an increase in UV radiation penetration [11].

2.7 Washing
Generally, washing increases the fabric UPF value. The effect of washing is particularly significant for cotton and poly-cotton fabrics, which exhibit a permanent increase in their UPF after the first washing cycle [11,16]. On the contrary, the UPF of bleached cotton fabrics does not significantly change with washing [12]. The increase of the UPF after the first laundering may be explained by the shrinkage that occurs in the fabric structure and the slip of some fiber ends outside the yarn as a result of the mechanical stresses that undergoes the fabric during laundering. Both of these phenomena will decrease the fabric porosity and consequently increase the UPF.
2.8 **UVR absorbing additives (agents)**
Special fabric treatments with chemical additives that absorb UVR can be used in order to increase the UV protection performance of garments. UV absorbers are substances, such as substituted benzothiazoles, which selectively absorb UV radiation and convert it to heat [11]. For permanent results, UV absorbers should be attached to the fibers with strong covalent bonds. Special treatments of Cotton with nanoparticles of Zinc oxide (ZnO) or Titanium dioxide (TiO2) can also be applied resulting higher levels of UV blocking [18-19]. In the case of synthetic fibers, special pigments such as Titanium dioxide (TiO2) can be incorporated into the fiber mass during the manufacturing process, offering permanent UV protection performance [17-19]. Finally as already mentioned, special dyes with an absorption spectrum within the UV range may also be used as UV absorbers.

2.9 **Yarn morphology**
According to older considerations, the UV transmission through yarns is practically zero. However, more recent research showed that the yarn morphology has an impact in fabric UPF. Yarns made of more wavy filaments have a structure that allows higher UV transmission levels. Higher twists make yarns more compact but create a more irregular surface, which prevents the closer packing of the yarns during the weaving process and results in an increased fabric porosity [14]. The yarns that are used in knitting are less twisted and their less compact structure may allow higher UV transmission levels. Thus, in order to be more accurate regarding the porosity of knitted fabrics the bulk density of the knits, $\rho_k$ (g/cm³) is taken into account, and the total porosity P (%) is defined as the portion of all air spaces in the fabric both between yarns and inside them [3].

3. **Materials and methods**
For the purposes of this research, 14 typical weft-knitted structures were considered, as presented in Table 2. For each one of them two samples were constructed, one by using a 2-ply yarn and another one by using a 3-ply yarn. For the Interlock structure, only one sample with a 2-ply yarn was constructed. In total 27 different knitted fabric samples have been constructed in a flat knitting machine STOLL CMS 411.6 - 7 Gauge.

The material used was grey yarns made of 100% Organic Cotton, Ne 30/2, 330 TPM, which have been offered by the Greek cotton industry VARVARESSOS S.A. The selection of the particular material has been made due to the increasing market interest for Organic Cotton products. In order to achieve the main target of our research, which is to verify the knit structures that can offer the highest possible UV protection, undyed grey yarns was chosen as the most proper option, since a different dyeing in any shade will increase even more the fabric UPF.

| Knit Structure | Technical Front | Technical Back | Knitting Notation |
|----------------|----------------|----------------|------------------|
| Single Jersey  | ![Image](image1.png) | ![Image](image2.png) | ![Image](image3.png) |
| Lacoste         | Full Cardigan          | Half Cardigan          |
|-----------------|------------------------|------------------------|
|                 |                        |                        |
| Full Milano     |                        |                        |
| Half Milano     |                        |                        |
| Pineapple       |                        |                        |
| KM22C           |                        |                        |
The in vitro UV transmittance measurements have been realized in a Varian Cary 5000 UV-Vis-NIR spectrophotometer, equipped with integrating sphere. Measurements made in the range from $\lambda_{\text{min}} = 290$ nm to $\lambda_{\text{max}} = 400$ nm with a step of $\Delta \lambda = 5$ nm. Since measurements concern non-bleached and non-dyed samples, no band-pass filter UG-11 for fluorescent materials has been used.
For the sample measurement and evaluation procedures the “European Standard EN 13758-1:2001 Textiles - Solar UV protective properties - Part 1: Method of test for apparel fabrics” has been followed.

Specimens handling was gentle and all measurements have been made with the fabric under no stress. No special conditioning has been applied to the specimens before the measurement, but specimens’ storage and measurements have been realized in a laboratory environment with controlled conditions of temperature 25 +/- 2°C and relative humidity 55 +/- 5 % RH. The laboratory is accredited for UV assessments.

Because any of the two sides of a knitted fabric may be used in the external face of a garment for creating different “fashion” effects, measurements have been made in both sides of the samples. Since in most knitted structures, each technical side has a different appearance and texture, the more strict evaluation method for “Non-uniform samples” as described in the European Standard EN 13758-1:2001 was followed. According to this method, in materials that contain areas of different shades or construction, at least two specimens of each colour and of each texture area shall be tested and the lowest UPF measured value is considered the material’s UPF [5]. For each knitted structure eight measurements have been made, four in the technical front and four in the technical back.

4. Results and discussion

Seven structures have been found with high UPF values (figure 1). Three of them, the Full Milano and KM22W with 3-ply yarn and the Interlock with 2-ply yarn exhibited UPF > 50, while the Half Cardigan, KM11, KM22C and Rib 1x1 with 3-ply yarn exhibited UPF > 40.

Observation of the measured data gave no clear evidence of the UV blocking superiority of either the technical front or the technical back side for almost all the evaluated structures, except KM22W, Full Milano and to some degree Cardigan, which exhibit significantly different performance in each side. More specifically, KM22W exhibits higher UPF in its technical back, while Full Milano and Cardigan in their technical front. Single Jersey showed a slightly better performance in its technical back.

![Figure 1. Minimum UPF values calculated for each knitted structure with 2x or 3x yarn](image)

The maximum UVA and UVB, which correspond to the minimum UPF, of each knitted structure are depicted in the next figures 2 and 3 respectively.
The technical textile parameters of the evaluated samples along with their respective UVA, UVB and UPF values are presented in table 3. The use of thicker yarns (3-ply instead of 2-ply) increases dramatically UV protection performance of all knitted structures. Thicker yarns produce thicker and heavier fabrics with improved UV blocking capacity. However, this improvement depends upon the specific knitted structure that is used. For instance, the Half Cardigan structure, despite its lower loop density, weight and thickness in comparison with the Half Milano structure, presents a four times higher UPF when using 3-ply instead of 2-ply yarns, while the Half Milano presents a twice higher UPF. Another example indicating the structure configuration as the dominant parameter that affects the UPF, is the case of the lighter Rib 1x1 structure with a 2-ply yarn, which provides a higher UPF than the heavier Lacoste structure with a 3-ply yarn.

The presence of miss stitches in the knit structure seems to be related with an increased UV blocking effect. All evaluated structures which contain miss stitches, i.e. KM11, KM22C and KM22W, exhibited high UPFs. On the other hand, tuck stitches certainly affect the UPF, but their positive or negative effect depends on how they are combined and repeated within the structure. From all the evaluated structures which contain tuck stitches, only Half Cardigan reached a UPF above 40.
Table 3. Textile parameters of the samples along with their respective UVA$_{max}$, UVB$_{max}$ and UPF$_{min}$

| KNIT TYPE       | Course /cm | Wales /cm | Loops /cm$^2$ | Weight gr/m$^2$ | Thickness mm | UVA (max) | UVB (max) | UPF (min) |
|-----------------|------------|-----------|---------------|----------------|--------------|-----------|-----------|-----------|
| Plain Jersey x2 | 6          | 5         | 30            | 178.5          | 0.85         | 16.447    | 12.705    | 7.342     |
| Plain Jersey x3 | 5.9        | 4.5       | 26.55         | 254.9          | 1.1          | 9.809     | 7.487     | 12.429    |
| Lacoste x2      | 6          | 3.5       | 21            | 162.8          | 1.76         | 23.947    | 20.526    | 4.640     |
| Lacoste x3      | 5          | 3.5       | 17.5          | 299.6          | 1.85         | 10.629    | 8.838     | 10.657    |
| Full Cardigan x2| 5          | 5         | 25            | 228.3          | 0.96         | 11.028    | 7.917     | 11.603    |
| Full Cardigan x3| 5          | 4         | 20            | 329.4          | 1.66         | 6.828     | 4.519     | 19.899    |
| Half Cardigan x2| 4.2        | 4.5       | 18.9          | 236.1          | 1.15         | 14.650    | 10.861    | 8.557     |
| Half Cardigan x3| 4.2        | 4.5       | 18.9          | 344            | 1.95         | 3.836     | 2.143     | 41.002    |
| Full Milano x2  | 5          | 8         | 40            | 304.8          | 1.45         | 7.693     | 5.690     | 16.167    |
| Full Milano x3  | 6          | 8         | 48            | 442.6          | 1.96         | 2.296     | 1.277     | 68.807    |
| Half Milano x2  | 7          | 8         | 56            | 265.9          | 1.45         | 10.942    | 8.098     | 11.435    |
| Half Milano x3  | 7          | 8         | 56            | 419.5          | 2.17         | 5.044     | 3.685     | 24.941    |
| Pineapple x2    | 5          | 4         | 20            | 165.8          | 0.91         | 22.437    | 18.718    | 5.061     |
| Pineapple x3    | 5          | 4         | 20            | 314            | 1.65         | 9.718     | 7.874     | 11.946    |
| KM22C x2        | 5.5        | 5         | 27.5          | 240            | 1.08         | 7.525     | 5.216     | 17.457    |
| KM22C x3        | 7          | 4.7       | 32.9          | 412.2          | 1.51         | 2.768     | 1.944     | 48.595    |
| KM22W x2        | 5.5        | 5.9       | 32.45         | 204            | 1.02         | 11.040    | 8.507     | 10.866    |
| KM22W x3        | 7          | 5         | 35            | 423.7          | 1.54         | 1.761     | 0.927     | 93.448    |
| KM11 x2         | 5          | 5.3       | 26.5          | 207.8          | 1.02         | 11.142    | 8.534     | 10.904    |
| KM11 x3         | 6          | 5.5       | 33            | 370.5          | 1.42         | 3.132     | 1.844     | 47.902    |
| KT22C x2        | 5.8        | 3.6       | 20.88         | 222.1          | 1.5          | 11.268    | 8.015     | 11.404    |
| KT22C x3        | 6.5        | 3.5       | 22.75         | 367.2          | 1.89         | 6.572     | 5.070     | 18.335    |
| KT22W x2        | 4.2        | 4         | 16.8          | 140.2          | 0.77         | 23.755    | 19.914    | 4.759     |
| KT22W x3        | 4          | 4         | 16            | 243            | 1.45         | 11.411    | 8.847     | 10.525    |
| RIB 1:1 x2      | 5          | 8         | 40            | 178.5          | 0.82         | 7.376     | 4.601     | 19.499    |
| RIB 1:1 x3      | 5          | 7         | 35            | 383.7          | 1.89         | 3.510     | 2.059     | 42.729    |
| Interlock x2    | 5.3        | 6         | 31.8          | 361.4          | 1.69         | 3.140     | 1.667     | 51.359    |

The above mentioned structures with UPF > 40 are expected to exhibit relative high UPFs also when used in finer gauge fabrics. This assumption is also supported by previous research on finer gauge knitted fabrics [8, 9]. Although the thinner samples knitted with 2-ply yarn showed significantly lower UPFs, a selection among these structures can be considered as the optimum starting point in the design of finer gauge knitwear with a relative high UPF which then can be further improved by optimizing other fabric engineering parameters. By using one of these structures, it is expected that the final knitwear will have a high UPF, since coloration and post-knitting wet treatments will further increase the UPF. The final finishing stage of ironing is anticipated to increase even more the UPF, but it has to be confirmed in a future research.

To understand better the protection level that is offered by the various knitted structures across the entire UVR spectrum, the measured Transmittance (T%) over evenly incremented wavelength intervals is presented in the following table 4 and figure 4 for the knitted samples with 2-ply yarn and in table 5 and figure 5 for the knitted samples with 3-ply yarn. All the knit structures show a transmittance increase as the wavelength increases, especially above 350 nm, resulting lower protection levels in the UVA region.
Table 4. UVR Transmittance (%) of the knit structures with 2-ply yarn

| $\lambda$ (nm) | KT22W | Lacoste | Pineapple | Single Jersey | Half Cardigan | KM11 | KM22W | KT22C | Cardigan | Half Milano | KM22C | Full Milano | Rib 1:1 | Interlock |
|----------------|-------|---------|-----------|---------------|---------------|------|-------|-------|-----------|-------------|-------|-------------|--------|-----------|
| 290            | 17.19 | 17.21  | 14.82     | 10.60         | 8.21          | 7.12 | 7.05  | 6.44  | 5.80      | 5.51        | 4.38  | 3.98        | 2.54   | 1.06       |
| 295            | 17.77 | 17.76  | 15.33     | 11.06         | 8.56          | 7.44 | 7.38  | 6.78  | 6.13      | 5.77        | 4.62  | 4.20        | 2.72   | 1.16       |
| 300            | 18.33 | 18.28  | 15.84     | 11.51         | 8.91          | 7.79 | 7.73  | 7.12  | 6.44      | 6.05        | 4.86  | 4.40        | 2.93   | 1.27       |
| 305            | 18.87 | 18.80  | 16.31     | 11.90         | 9.24          | 8.10 | 8.04  | 7.45  | 6.75      | 6.31        | 5.11  | 4.63        | 3.10   | 1.38       |
| 310            | 19.35 | 19.27  | 16.74     | 12.32         | 9.57          | 8.41 | 8.37  | 7.78  | 7.06      | 6.56        | 5.34  | 4.82        | 3.28   | 1.49       |
| 315            | 19.83 | 19.72  | 17.19     | 12.72         | 9.89          | 8.72 | 8.67  | 8.10  | 7.36      | 6.82        | 5.57  | 5.03        | 3.47   | 1.62       |
| 320            | 20.31 | 20.17  | 17.59     | 13.11         | 10.18         | 9.06 | 8.96  | 8.43  | 7.66      | 7.06        | 5.78  | 5.22        | 3.69   | 1.73       |
| 325            | 20.74 | 20.62  | 18.02     | 13.48         | 10.50         | 9.20 | 9.20  | 8.75  | 7.96      | 7.30        | 5.98  | 5.37        | 3.87   | 1.84       |
| 330            | 21.22 | 21.06  | 18.45     | 13.88         | 10.84         | 9.45 | 9.48  | 9.06  | 8.28      | 7.56        | 6.20  | 5.56        | 4.06   | 1.97       |
| 335            | 21.70 | 21.49  | 18.86     | 14.26         | 11.16         | 9.76 | 9.78  | 9.41  | 8.62      | 8.22        | 6.43  | 5.77        | 4.29   | 2.11       |
| 340            | 22.03 | 21.83  | 19.20     | 14.60         | 11.45         | 10.02 | 9.68 | 8.88  | 8.06      | 6.69        | 5.97  | 4.51        | 2.25   | 0.94       |
| 345            | 22.52 | 22.27  | 19.59     | 15.01         | 11.82         | 10.25 | 9.52 | 8.72  | 7.94      | 6.95        | 6.22  | 4.75        | 2.39   | 0.97       |
| 350            | 22.76 | 21.93  | 20.12     | 15.21         | 12.16         | 10.68 | 10.27 | 9.43  | 8.62      | 7.09        | 6.31  | 5.06        | 2.48   | 0.90       |
| 355            | 23.21 | 22.36  | 20.55     | 15.62         | 12.52         | 11.02 | 10.63 | 9.79  | 8.93      | 7.39        | 6.56  | 5.33        | 2.66   | 0.95       |
| 360            | 23.66 | 22.78  | 20.97     | 16.04         | 12.88         | 11.37 | 11.00 | 10.17 | 9.24      | 7.70        | 6.83  | 5.62        | 2.85   | 0.98       |
| 365            | 24.10 | 23.21  | 21.38     | 16.45         | 13.25         | 11.72 | 11.38 | 11.40 | 10.54     | 9.55        | 8.01  | 7.09        | 5.90   | 3.04       |
| 370            | 24.54 | 23.63  | 21.80     | 16.87         | 13.63         | 12.08 | 11.75 | 11.79 | 10.92     | 9.87        | 8.32  | 7.36        | 6.20   | 3.24       |
| 375            | 24.96 | 24.04  | 22.21     | 17.28         | 14.01         | 12.43 | 12.12 | 12.17 | 11.30     | 10.19       | 8.64  | 7.63        | 6.50   | 3.45       |
| 380            | 25.38 | 24.46  | 22.62     | 17.70         | 14.40         | 12.78 | 12.48 | 12.55 | 11.69     | 10.51       | 8.95  | 7.91        | 6.81   | 3.67       |
| 385            | 25.81 | 24.87  | 23.03     | 18.12         | 14.79         | 13.15 | 12.88 | 12.95 | 12.08     | 10.85       | 9.29  | 8.20        | 7.14   | 3.90       |
| 390            | 26.21 | 25.26  | 23.43     | 18.54         | 15.17         | 13.53 | 13.27 | 13.34 | 12.47     | 11.20       | 9.64  | 8.50        | 7.47   | 4.14       |
| 395            | 26.59 | 25.65  | 23.81     | 18.94         | 15.55         | 13.91 | 13.67 | 13.72 | 12.86     | 11.53       | 9.99  | 8.80        | 7.80   | 4.39       |
| 400            | 26.96 | 26.02  | 24.18     | 19.34         | 15.92         | 14.29 | 14.06 | 14.10 | 13.24     | 11.87       | 10.35 | 9.12        | 8.14   | 4.64       |

Figure 4. Transmittance T% in the UVR spectrum of the knitted structures with 2-ply yarn
Table 5. UVR Transmittance (T%) of the knit structures with 3-ply yarn

| $\lambda$ (nm) | KT22W | Pineapple | Lacoste | Single Jersey | KT2C | Cardigan | Half Milano | Half Cardigan | RIB 1:1 | KM11 | KM22C | Full Milano | KM22W |
|----------------|-------|-----------|--------|---------------|------|----------|-------------|--------------|---------|-------|-------|-------------|-------|
| 290            | 6.51  | 6.97      | 6.26   | 6.03          | 3.88 | 2.83     | 2.29        | 1.19         | 1.18    | 1.43  | 1.40  | 1.05        | 0.58  |
| 295            | 6.84  | 7.24      | 6.56   | 6.33          | 4.07 | 3.04     | 2.40        | 1.30         | 1.28    | 1.54  | 1.48  | 1.12        | 0.64  |
| 300            | 7.14  | 7.51      | 6.84   | 6.61          | 4.28 | 3.22     | 2.54        | 1.40         | 1.38    | 1.65  | 1.59  | 1.20        | 0.70  |
| 305            | 7.44  | 7.76      | 7.12   | 6.86          | 4.47 | 3.42     | 2.67        | 1.50         | 1.49    | 1.75  | 1.68  | 1.28        | 0.74  |
| 310            | 7.75  | 7.99      | 7.37   | 7.10          | 4.66 | 3.61     | 2.77        | 1.62         | 1.59    | 1.83  | 1.77  | 1.36        | 0.81  |
| 315            | 8.02  | 8.22      | 7.62   | 7.36          | 4.84 | 3.79     | 2.90        | 1.73         | 1.71    | 1.93  | 1.86  | 1.44        | 0.85  |
| 320            | 8.31  | 8.42      | 7.86   | 7.60          | 5.01 | 3.97     | 3.01        | 1.84         | 1.81    | 2.02  | 1.96  | 1.51        | 0.93  |
| 325            | 8.56  | 8.62      | 8.06   | 7.85          | 5.17 | 4.15     | 3.11        | 1.96         | 1.92    | 2.11  | 2.03  | 1.59        | 0.97  |
| 330            | 8.83  | 8.83      | 8.29   | 8.09          | 5.36 | 4.35     | 3.23        | 2.08         | 2.01    | 2.20  | 2.13  | 1.66        | 1.05  |
| 335            | 9.13  | 9.05      | 8.57   | 8.36          | 5.56 | 4.59     | 3.35        | 2.21         | 2.16    | 2.31  | 2.21  | 1.75        | 1.12  |
| 340            | 9.36  | 9.25      | 8.79   | 8.56          | 5.73 | 4.75     | 3.49        | 2.36         | 2.28    | 2.40  | 2.34  | 1.86        | 1.16  |
| 345            | 9.71  | 9.48      | 9.08   | 8.84          | 5.89 | 4.99     | 3.62        | 2.51         | 2.43    | 2.53  | 2.44  | 1.94        | 1.26  |
| 350            | 9.70  | 9.39      | 8.95   | 8.81          | 5.86 | 5.07     | 3.63        | 2.60         | 2.53    | 2.68  | 2.49  | 2.03        | 1.36  |
| 355            | 10.02 | 9.63      | 9.23   | 9.08          | 6.08 | 5.33     | 3.77        | 2.77         | 2.70    | 2.82  | 2.62  | 2.14        | 1.46  |
| 360            | 10.36 | 9.87      | 9.51   | 9.36          | 6.30 | 5.59     | 3.92        | 2.95         | 2.86    | 2.96  | 2.76  | 2.27        | 1.56  |
| 365            | 10.69 | 10.12     | 9.80   | 9.65          | 6.52 | 5.85     | 4.08        | 3.13         | 3.03    | 3.11  | 2.90  | 2.39        | 1.67  |
| 370            | 11.02 | 10.36     | 10.07  | 9.94          | 6.75 | 6.12     | 4.23        | 3.32         | 3.21    | 3.26  | 3.05  | 2.51        | 1.78  |
| 375            | 11.36 | 10.60     | 10.35  | 10.22         | 6.98 | 6.39     | 4.39        | 3.52         | 3.39    | 3.41  | 3.20  | 2.64        | 1.89  |
| 380            | 11.69 | 10.86     | 10.64  | 10.52         | 7.20 | 6.67     | 4.56        | 3.73         | 3.58    | 3.57  | 3.36  | 2.78        | 2.02  |
| 385            | 12.04 | 11.11     | 10.93  | 10.82         | 7.45 | 6.97     | 4.74        | 3.95         | 3.78    | 3.75  | 3.53  | 2.93        | 2.15  |
| 390            | 12.38 | 11.38     | 11.24  | 11.12         | 7.70 | 7.27     | 4.92        | 4.17         | 3.99    | 3.92  | 3.71  | 3.08        | 2.29  |
| 395            | 12.74 | 11.64     | 11.53  | 11.42         | 7.95 | 7.57     | 5.11        | 4.40         | 4.21    | 4.11  | 3.89  | 3.24        | 2.44  |
| 400            | 13.08 | 11.91     | 11.84  | 11.71         | 8.20 | 7.88     | 5.30        | 4.64         | 4.43    | 4.31  | 4.08  | 3.41        | 2.60  |

Figure 5. Transmittance T% in the UVR spectrum of the knitted structures with 3-ply yarn
5. Concluding Remarks

As expected, the use of thicker yarns (3-ply instead of 2-ply) results to increased UV protection performance of the fabric. However, the comparison between different samples leads to the following conclusions:

- Knit fabric structure has the greatest influence in the UPF. The presence of miss stitches seems to be related with an increased UV blocking performance, since all the evaluated structures with miss stitches exhibited high UPFs.
- Tuck stitches, although are generally associated with low UPFs, may have a positive or negative effect depending on how they are combined and repeated within the knit structure.
- Seven knit structures have been found with UPF > 40, namely, Half Cardigan. Full Milano, Rib 1x1, KM11, KM22C, KM22W with 3-ply yarn and Interlock with 2-ply yarn, with three of them reaching UPF values above 50 (Full Milano, KM22W and Interlock). By using one of these structures we can be pretty sure that the final knitwear will have a high UPF, taking into consideration that coloration and post-knitting wet treatments, like washing, will further increase the UPF.
- The final finishing stage of ironing is expected to increase even more the UPF, but it has to be confirmed in a future research.

Finally, it is worth mentioning that in all knit structures a transmittance increase is observed as the wavelength increases, especially above 350 nm, resulting in lower protection levels in the UVA region.

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