Effect of Fibers and Weave Designs on the Thermo-Physiological Comfort of Summer Scarf Fabric

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1. Introduction

Clothing is the basic need for humans that provides cover and protection to human body against external environment. The selection of clothing depends on the desire and need of the human. The choice for the clothing changes with the season, age, work and activity type, climate, and fashion [1]. The fundamental demand of the clothing is the comfort which can be defined as a pleasant state of psychological, physiological, and physical harmony between a human body and the environment [2]. The categories of comfort are sensorial/tactile comfort, psychological comfort, and thermo-physiological comfort [3]. The ability of fabric to allow air, perspiration, and heat through it is known as thermo-physiological comfort. The air permeability, thermal resistance, and water vapor permeability determine the passage of air, heat, and perspiration through fabric, and these properties depend upon the fiber nature, yarn type, fabric structure, and chemical coatings on fabric [4, 5].

The movement of heat, air, and moisture in vapor and liquid form through the fabric can be utilized for the assessment of thermo-physiological comfort of fabric [6]. Fiber type, cross-sectional shapes of fibers, and their blends have significant impact on the air permeability, thermal resistance, and moisture absorption [7–9]. Moisture transportation and thermal properties of the fabric also depend upon the type of yarn, fabric weight, thickness, and weave structure. The structural parameters of woven fabric have great influence on apparel selection either for winter or summer season [10–12].

The strength and durability of the fabric is also a factor for the selection of apparel as many other factors such as color, appearance, comfort, and cost. Tear strength and tensile strength are the mechanical properties which determine the strength criteria for the fabric, and these properties also depend upon the fiber type, yarn type, fabric construction method, and nature of any coating or finish applied on it [13–17].

Textile fibers are the fundamental unit of any textile-based product. The natural and synthetic fibers and their blends are usually used to construct a textile assembly [5]. The selection of textile fibers is very important in order to
achieve the desired properties of a fabric. The type of fiber significantly affects the mechanical and comfort properties of textiles [18]. COOLMAX® is a modified polyester fiber, which has excellent comfort properties due to its unique structure. This fiber transfers moisture very quickly from the skin by pulling it towards the fabric and dries out from the fabric surface due to its unique channeled structure. That is why COOLMAX® is a good choice for summer clothing [19].

TENCEL™ is a regenerated cellulosic fiber, which has good tensile and tear strengths and biodegradability. This fiber also has good comfort properties due to its porous structure [20–23], which is suitable for summer fabrics. The micropolyester fiber has poor air permeability but has good water vapor permeability and moisture management properties due to its lower fiber diameter [24–26]. Bamboo fiber is another regenerated fiber, which is obtained from the bamboo plant. Moreover, bamboo fiber is biodegradable and has antibacterial properties [27]. The high moisture absorption capacity and UV resistance make the bamboo fiber attractive for summer fabrics [28].

Headscarves and headwraps are some of the clothing articles which are highly attractive and useable among female fashion and apparels. There are three important dimensions related to the comfort of the headscarf, i.e., aesthetic, tactile comfort, and thermal comfort. The aesthetic value of a garment has a direct relationship with the fabric drape which is dependent on the fabric stiffness. Tactile comfort may indirectly be determined using the surface friction of the fabrics with which the garments are produced. There are several evaluation techniques to find out the thermal comfort. Some of them are thermal resistance, overall moisture management capability (OMMC), and air permeability. The market survey revealed that polyester fiber is widely being used to produce summer headscarf. A polyester headscarf usually has a good aesthetic value, but it has poor tactile and thermal comfort properties. As the scarves are in direct contact with the skin, polyester may cause itching, abrasion, friction, and other uncomfortable feelings due to the production of static charge on it. Therefore, there is a need to propose summer scarf fabrics with improved comfort and good drape. The aim of this study is to develop and compare properties of scarf fabrics, which are prepared by using different textile fibers and fabric structures with better thermal and tactile comfort.

2. Materials and Methods

2.1. Materials. Four different fibers (COOLMAX®, TENCEL™, micropolyester, and bamboo) were used to produce carded ring spun yarns of tex 10/1 count in a Toyoda R-4 ring frame. The technical specifications of fibers are given in Table 1.

A total of 12 woven samples having three different weave designs, i.e., 1/1 plain, 2/1 twill, and 2/2 matt, were manufactured as shown in Figure 1. The areal density (g/m²) of the fabrics ranged from 65–74 g/m² which is suitable for summer seasons. Similar yarns having same count, i.e., Ne 60/1, were used in both warp and weft directions. Weft density (PPI) was kept less than the warp density (EPI) because picks higher than ends are scarcely used in commercial weaving. The technical specifications of the fabrics used are given in Table 2. All fabric samples were manufactured on the sample weaving loom (Evergreen, CCI Taiwan).

2.2. Methods. Desizing of the fabric was done using hot water treatment. The detergent was added to achieve detergency to remove the oil and dust from the fabric. The concentration of detergent used was 2 g/L. The process temperature was 90°C, and the process was carried out for 1 hour. After that, the samples were washed with cold water to remove detergent. It was then squeezed between the lab scale padder to remove excess water and then dried on lab scale machine. The drying temperature was 70°C, and dwell time was 1 minute.

2.3. Characterization

2.3.1. Yarn Testing. The yarn count was tested in accordance with ISO 2060:1994 standard. Twist per inch (TPI) of the yarns was measured using standard ISO 17202:2002 (untwist/retwist standard test method). Tensile strength and elongation test of all the yarn samples were carried out using Uster Tensorapid-1 by Uster Technologies, Switzerland, following the ASTM D 2256-02 standard test method. Yarn unevenness, imperfections, and hairiness measurements of all the samples were done using Uster Tester-5 (UT-5) by Uster Technologies, Switzerland, following the ASTM D1425 standard test method.

2.3.2. Fabric Testing. The areal density of the fabric samples was measured according to ASTM D 3776 standard test methods. To determine moisture management properties, AATCC 195-2012 standard test method was followed. To measure air permeability of the samples, standard test method (ASTM D 737-04 (2008)) was followed. A test method (ISO 11092:1993) was used to determine the thermal resistivity of the fabric samples.

Surface coefficient of friction test was determined according to the ASTM D 1894-01 standard. Five specimens were tested for each woven sample. For each test, two specimens were cut. The specimen, to be tested, was cut of 250 x 130-mm size, and was smoothened to eliminate wrinkles, taking care that no alteration in the specimen surface occurs. The wrinkles were removed so that the surface remains smooth. The sample which was attached to the sled was cut at 120 mm². The sample was stretched lightly to remove any distortions on the surface of the fabric. The edges of the 120 mm² specimen were attached to the back of the sled, and then the specimen-covered sled was attached through its eye screw to the nylon filament. The drive speed for the apparatus was 150 mm/min. After this, the driving mechanism was started to provide a speed of 150 mm/min. Due to the presence of frictional forces between the contacting surfaces, no immediate realtive motion was observed.
This is due to the fact that lubrication on the sled is equal to or more than the static frictional force acting between the contacting surfaces. The reading of static and dynamic coefficient of friction was recorded.

The fabric drape test was performed according to BS 5058-1973 testing standard, on the Cusick drape tester. In this test, circular specimen of 30 cm diameter was used. This specimen was placed concentrically on the circular disc having 18 cm diameter and was allowed to drape under its own weight, above which there was the illumination source. The shadow cast by the fabric was traced to a piece of paper. The snap of this shadow was taken using the camera. The larger the area of the shadow is, the stiffer would be the fabric. The drape coefficient of the fabric was determined by using the following formula:

$$\text{DC\%} = \frac{[\text{area under the draped sample} - \text{area of support disk}]}{[\text{area of the specimen} - \text{area of support disk}]} \times 100.$$  

(1)

### 3. Results and Discussion

#### 3.1. Yarn Properties.

The physical and mechanical properties of the produced yarns are shown in Tables 3 and 4.

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**Table 1: Technical specifications of fibers.**

| S. No. | Property                  | TENCEL™ | Micropolyester | COOLMAX® | Bamboo |
|-------|---------------------------|---------|----------------|----------|--------|
| 1     | Length (mm)               | 38      | 38             | 38       | 38     |
| 2     | Linear density (denier)   | 1.44    | 1.17           | 1.00     | 1.19   |
| 3     | Breaking force (N)        | 0.169   | 0.103          | 0.159    | 0.079  |
| 4     | Tenacity (cN/tex)         | 99.83   | 43.68          | 91.82    | 25.36  |
| 5     | Elongation (%)            | 21.37   | 12.51          | 17.57    | 16.20  |

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**Table 2: Technical specifications of fabrics.**

| S. No. | Material       | Ends (EPI) | Picks (PPI) | Weight (g/m²) | Weave         | Thickness (mm) |
|-------|----------------|------------|-------------|---------------|---------------|----------------|
| 1     | Bamboo         | 102        | 74          | 73.67         | 2/1 Satin     | 0.26           |
| 2     | Bamboo         | 100        | 74          | 72.74         | 1/1 Plain     | 0.26           |
| 3     | Bamboo         | 104        | 76          | 75.20         | 2/2 Matt      | 0.22           |
| 4     | TENCEL™        | 98         | 67          | 67.58         | 2/1 Satin     | 0.24           |
| 5     | TENCEL™        | 95         | 67          | 66.32         | 1/1 Plain     | 0.24           |
| 6     | TENCEL™        | 102        | 67          | 69.25         | 2/2 Matt      | 0.20           |
| 7     | Micropolyester | 94         | 70          | 69.72         | 2/1 Satin     | 0.20           |
| 8     | Micropolyester | 100        | 70          | 67.72         | 1/1 Plain     | 0.20           |
| 9     | Micropolyester | 98         | 72          | 69.66         | 2/2 Matt      | 0.18           |
| 10    | COOLMAX®       | 100        | 73          | 70.93         | 2/1 Satin     | 0.20           |
| 11    | COOLMAX®       | 96         | 70          | 68.05         | 1/1 Plain     | 0.22           |
| 12    | COOLMAX®       | 102        | 72          | 71.38         | 2/2 Matt      | 0.22           |

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**Figure 1: Weave designs.**

3.2. Fabric Properties

3.2.1. Fabric Areal Density and Thickness. Areal density of all the fabrics is given in Figure 2 which shows that fabrics made up of bamboo and TENCEL™ have slightly
higher areal density than micropolyester and COOLMAX® fabrics. But there is no significant difference of areal density between the fabric samples. Plain weave and twill weave structures have almost same areal density, but matt weave has slightly lower areal density.

Figure 2 shows the thickness value of the fabrics. It is clear from Figure 3 that fabrics made up of bamboo and COOLMAX® fiber have more thickness than micropolyester and TENCEL™ fabrics. Twill weave fabrics have the highest value of thickness while matt weave have the lowest.

3.2.2. Air Permeability. Air permeability of all the fabrics is given in Figure 4, which indicates that TENCEL™ has highest values of air permeability while micropolyester has the lowest value. The lowest value of micropolyester may be due to the fact that the microfibers have large surface area, which reduces the passage of air current through the fabric as compared to the other fibers while TENCEL™ possesses the lowest bulk value which causes air to pass through it easily. On the other hand, bamboo fiber has second highest air permeability value due to its microporous structure [29]. COOLMAX® fiber has more air permeability than micropolyester fiber because of its grooved structure [30]. Similarly, due to the more compact structure of the plain weave, there are fewer pores available in the fabric to allow air to pass through it. Hence, in this case, it shows the lowest value of air permeability. Matt weave is suitable for summer clothing as it possesses lowest resistance to the air passing through it due to lower number of yarn intersection and loose fabric structure.

3.2.3. Thermal Resistance. The effect of weave design and the fiber nature on the thermal resistance is given in Figure 5. Bamboo and micropolyester fibers have higher values of thermal resistance as compared to TENCEL™ and COOLMAX® fibers. Figure 3 showed that the fabric made of bamboo fibres have the highest value of fabric thickness. Higher thickness makes the fabric more heat resistant.

| Table 3: Physical and mechanical properties of yarns. |
|-------------|-------------|-------------|-------------|-------------|
| S. No.      | Parameter   | TENCEL™     | Micropolyester | COOLMAX®   | Bamboo      |
| 1           | Count (Ne)  | 61.70       | 61.61         | 61.59       | 60.33       |
| 2           | Twist per inch (T.P.I) | 28.93       | 25.18         | 27.78       | 29.05       |
| 3           | Single yarn strength (cN) | 158.1       | 217.1         | 133.7       | 110.7       |
| 4           | Elongation (%) | 5.39        | 7.57          | 9.21        | 8.41        |
| 5           | Tenacity (cN/tex) | 16.07       | 22.64         | 13.59       | 10.94       |
| 6           | CLSP        | 2429.68     | 3520.28       | 2054.70     | 1701.24     |

| Table 4: Yarn imperfections. |
|-------------|-------------|-------------|-------------|-------------|
| S. No.      | Parameter   | TENCEL™     | Micropolyester | COOLMAX®   | Bamboo      |
| 1           | Unevenness (U%) | 13.06       | 11.60         | 13.68       | 14.27       |
| 2           | CVm (%)     | 16.66       | 14.58         | 17.20       | 18.04       |
| 3           | Thick (-50%) | 54          | 52.5          | 148.5       | 203.5       |
| 4           | Neps (+200%) | 495.5       | 57            | 73.5        | 377.5       |
| 5           | Imperfections/km | 776.5       | 4.55          | 5.03        | 4.58        |

Figure 2: Areal density of fabrics made using different fibers and weave designs.

Figure 3: Thickness of fabrics made using different fibers and weave designs.
Micropolyester is micro denier fiber, which has high surface area, trapping more air inside the structure, which ultimately lowers the heat flow. The plain weave fabric has the highest thermal resistance, while the matt weave has the lowest. The plain weave fabric has maximum interlacement points between warp and weft yarns which helped to hinder the flow of heat. On the contrary, matt weave has the lowest thermal resistance because of less number of yarn interlacements between warp and weft. The twill weave has intermediate values of thermal resistance due to the less compact structure as compared to plain weave but more cover factor as compared to matt weave.

3.2.4. Moisture Management Properties. The results for OMMC (overall moisture management capacity) are given in Figure 6 which indicate that the micropolyester fabrics have greater OMMC values than the other fabrics. Micropolyester fibers have good moisture wicking properties which are due to their higher packing coefficient than normal fibers. The average capillary size is less in the form of micropolyester spun yarn, which increases the capillary pressure and ultimately rapid moisture transportation. Moreover, the cellulose-based fibers (TENCEL™ and bamboo) have higher moisture content values as they are highly moisture absorbent and take long time to transmit resulting in poor OMMC. There was no clear trend between the weave type and OMMC of the prepared fabrics. Wetting time for all the fabrics is given in Figure 7 which shows that the wetting time is higher for micropolyester and COOLMAX® fibers while it is lower for the cellulosic (TENCEL™ and bamboo) fibers. This may be due to their hydrophilicity of cellulosic material having bonding sites to attract water.

3.2.5. Fabric Drape. Fabrics with better drape result in better aesthetic value of a finished garment. The drape of the fabrics has a direct relation with the fabric stiffness, which is mainly affected by the type of fiber, yarn structure, fabric structure, and chemical finishes. The drape coefficient and appearance of draped fabric were used to determine the drape properties of the prepared fabrics. Figure 8 indicates that the fabric made of micropolyester possesses lower drape coefficient values while bamboo possesses the highest drape coefficient values among all the fabrics. This may be due to the fineness of the micropolyester fibers which possess lower coefficient values because fabrics made of finer fibers are less stiff than those made with coarser ones. Fabrics made from bamboo fibers possess a slightly higher areal density (g/m²), which may have resulted in higher drape coefficient value. Due to the more compact structure of the plain weave, highest value of drape coefficient was observed which may be due to the fact that its compact structure does not allow the movement of yarns and hence resists more to bend under its own weight, thus providing higher values of drape coefficient. The lower number of yarn intersections and loose fabric structure give the lowest value of drape coefficient for matt wave which was also confirmed by the images of fabric in Figure 9. Figure 9 represents the images of the draped fabric samples. A 30 cm circular sample of fabric was placed on a circular plate of 18 cm diameter. The shape of fabric draped by its own weight is shown in Figure 9. It can be observed that the plain-woven sample has poor drape while the matt woven sample depicted the best drape among the samples.
3.2.6. Fabric Surface Friction. Surface friction has a great impact on the tactile comfort of the garments. Fabrics with low surface friction provide better tactile comfort and can be used for the garments which come directly in contact with the skin. Figures 10 and 11 present the results for the static and dynamic friction, respectively. The results depict that the micropolyester fabric has the lowest coefficient of friction while TENCEL™ fabric has the highest coefficient of friction among all the fabrics.

This surface smoothness of the micropolyester is responsible for its lowest surface coefficient values. It was given in Table 4 that the micropolyester yarn had minimum hairiness and least imperfection value.
The plain-woven fabrics offered the highest surface friction while the matt woven fabric had the lowest surface friction. Fabric surface smoothness depends upon the number of yarn intersections in the fabric structure. Higher intersections elevate the fabric compactness, and hence the more the intersections, the more the surface friction due to the rough surface.

4. Conclusion

Three weave structures and four types of fibers were evaluated for aesthetic, tactile, and thermal comfort properties of a summer scarf fabric. The results revealed that matt weave is the best choice for a summer scarf fabric as it represented the lowest drape coefficient, surface friction, and thermal resistance values. This way the matt weave will depict excellent aesthetic, tactile, and thermal resistance properties. Further, micropolyester performed the best, among the selected fibers, for drape, surface friction, and overall moisture management capability (OMMC). On the other hand, TENCEL™ illustrated outstanding performance with respect to thermal resistance and air permeability. Micropolyester can be selected, if there is a limitation to use a single fiber. Otherwise, a blend of micropolyester and TENCEL™ may be used to achieve exceptional results in all three aspects, i.e., aesthetic, tactile comfort, and thermal comfort. Another study may be conducted to find out the best blend ratio among micropolyester and TENCEL™. In a nutshell, the summer scarf fabric should be woven (matt weave) and made of micropolyester and TENCEL™ blend.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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