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Research Article

Functional Analysis of Sportswear Materials from Natural and Regenerated Cellulose Yarns

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Abstract – The knitted sportswear market is rapidly evolving due to technological advancements and changing consumer demands for comfort, performance, and style. This study compares materials made from natural cotton and regenerated cellulose fibres (viscose and modal) to identify suitable alternatives to polyester. In the experimental part of the study, a number of material properties was evaluated, more precisely, thickness, porosity, bending rigidity, breaking force and elongation, abrasion resistance, compressibility, heat resistance, water vapour transfer and wetting time. The normalized values of investigated properties underscored the unique advantages of each material type - viscose material performed best in strength and heat-related properties, cotton material provided a well-rounded balance, and modal material comfort-related properties. Therefore, the choice of material should align with whether the application prioritizes durability, versatility, or comfort. The conducted PCA analysis confirmed distinct differences between viscose and modal materials, with cotton positioned between them.

Keywords – Fibre, Yarn, Material, Functional, Properties, PCA Analysis.

I. INTRODUCTION

One of the defining characteristics of contemporary knitted sportswear is its focus on breathability and moisture-wicking capabilities. Modern knitted fabrics, often made from synthetic fibers like polyester and polyamide or blended with natural fibers such as merino wool, promote air circulation and efficiently manage perspiration. This helps regulate body temperature and keeps athletes cool and dry during intense activity, enhancing both comfort and performance. In the early days of sportswear, natural materials like silk, cotton, and wool were commonly used, offering only limited performance features. However, the advent of synthetic fibers and advancements in knitting technology revolutionized the industry. These innovations improved comfort and functionality, leading to widespread adoption of knitting as a preferred method for sportswear construction [1]. Polyester remains the most widely used fiber in sportswear and active wear due to its exceptional performance attributes. Other synthetic fibers such as polyamide, polypropylene, polyacrylonitrile, and elastane are also suitable for active wear. Synthetic fibers can be engineered with hollow structures or irregular cross-sections to enhance thermoregulation, or blended with natural fibers to improve tactile and sensory comfort [2,3]. Polyester, in particular, offers excellent dimensional stability, resistance to dirt and alkalis, and a soft hand feel. Although inherently hydrophobic and low in moisture absorption, polyester yarns are often chemically treated to enhance their moisture-wicking properties, making them ideal for base layers. Its high tenacity and durability also make it well-suited for high-impact and outdoor use. In wet or humid environments, polyester excels due to its natural water resistance. Finishing treatments can further enhance its hydrophobic qualities. Additionally, hollow polyester fibers trap air for thermal insulation, helping to retain body heat in cold weather. Crimped polyester fibers also serve this function by trapping warm air more effectively. Because of its ability to retain shape and provide insulation, polyester continues to be a top choice for performance-oriented sportswear [3].

Like in other fields, the sustainability has become a key focus in the sportswear industry, prompting a shift toward eco-friendly materials and production methods. Increasingly, brands are incorporating natural fibers due to their biodegradability and lower environmental impact compared to conventional synthetics. These fibers offer breathability, comfort, and thermoregulating properties, making them suitable for both active and casual wear. Additionally, innovations in fiber processing and sustainable farming practices are enhancing the performance and durability of natural materials, making them a viable alternative to traditional synthetic fabrics.

The contemporary knitted sportswear market is undergoing dynamic growth, fueled by technological innovation, evolving consumer lifestyles, and a growing emphasis on both performance and style. As more people embrace active routines, the need for apparel that offers comfort, functionality, and aesthetic appeal has significantly increased. This shift has been further amplified by the athleisure trend, which has blurred the boundaries between athletic and everyday wear. Consumers now seek versatile garments that can seamlessly transition from the gym to casual settings, driving demand for stylish and functional knitted sportswear. This growing demand is evident in market projections, with the global sports textiles market expected to expand at a compound annual growth rate of 13.14% from 2023 to 2027, while the performance knitwear segment is projected to grow at 6.1% over the same period [4,5]. Adding further momentum to this growth is the increasing demand for sustainability. As environmental concerns become more prominent, consumers are prioritizing eco-friendly choices. In response, many manufacturers are incorporating sustainable raw materials and greener production methods, positioning eco-conscious innovation as a key driver in the evolution of the sportswear industry.

Our previous research in this field primarily focused on investigating polymer-based materials used in sportswear, particularly those made from polyester and polyamide [6-10]. In this paper, the emphasis shifts to materials made from natural and regenerated cellulose fibers.

II. MATERIALS AND METHOD

To support the adoption of alternative materials beyond polyester, this study focuses on comparing fabrics made from natural fibres (specifically cotton) and regenerated cellulose fibres (namely viscose and modal). Key performance indicators for these three fibre types are summarized in Table 1. Cotton is a natural fiber derived from the cotton plant. It is known for its high moisture absorption, moderate softness, and good durability, especially in the wet state. However, cotton has low elasticity and tends to wrinkle easily, which can affect the appearance of garments without proper care.

Table 1. The comparison of cotton, viscose and modal fibers

Property	Cotton	Viscose	Modal
Raw Material	Cotton plant	Wood pulp	Beechwood pulp
Fiber Type	Natural	Regenerated cellulose	Regenerated cellulose
Moisture Absorption	High	High	Very high
Softness	Moderate	Soft	Very soft
Durability (dry/ wet state)	Good/High	Moderate/Low	Good/High
Elasticity	Low	Low	Moderate
Wrinkle Resistance	Low	Low	Moderate

Viscose, a regenerated cellulose fiber, is produced from wood pulp sources such as bamboo, beech, or pine. It offers high moisture absorption and a soft feel, making it comfortable to wear. While viscose is moderately durable when dry, it becomes weak when wet and has low elasticity and poor wrinkle resistance, requiring delicate handling. Modal, also a regenerated cellulose fibre, is made specifically from beechwood pulp and is considered a more advanced version of viscose. It stands out for its very high moisture absorption, exceptional softness, and enhanced durability, even when wet. With moderate elasticity and improved wrinkle resistance, modal offers better performance and comfort, making it suitable for both casual and active wear.

For the experimental part, three knitted materials were produced using the viscose, cotton and modal yarn with addition of elastane, 9% on average. For the production was used the single-cylinder circular knitting machine in gauge E30. The horizontal density of all materials equalled 16 loops per cm, while the vertical was in range 33-36 loops per cm. The properties measured to evaluate the produced materials with description of method used were as follows:

- Thickness - measured using the DM 2000 – Wolf thickness meter; the thickness was determined on 10 different spots troughout the material.
- Porosity - determined from the image taken using the Dino – Lite Pro Hr AM7000/AD7000 series using the MATLAB software.
- Bending rigidity – determined using the Pierce cantilever test; the testing was conducted on 10 specimens.
- Breaking force and elongation - tested using a Statimat M strength tester; specimens for testing were cut both in the wale direction and in the course direction and for each material examined, five measurements were made in each direction.
- Bursting force - for testing was used Apparecchi Branca tester; for each material, five circular specimens were tested.
- Mass loss due abrasion - to test the abrasion resistance, the Aquabrasion measuring device was used and the method of mass loss was selected. The results were observed after 2500 abrasion cycles.
- Compressibility - tested using the PicoPress measuring device; the testing was performed by placing the prepared samples on cylinders with the following circumferences: 240, 350, and 395 mm.
- Heat and water vapour resistance - tested using the sweating guarded hotplate apparatus using the three specimen for each property.
- Wetting Time – measured as the time needed for absorption of a liquid droplet applied with a pipette; for the measurement is used stopwatch and thermal camera Flir E5.

For the comparison of the results is used the normalized scale. The normalized scale transforms values of each property to a range between 0 and 1, allowing for easy comparison across different units and magnitudes, according to the following equation:

$$X_N = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

Where:
X_N - normalized value
X - measured value for a single property
X_{min} - minimum value for the observed property among observed dataset
X_{max} - maximum value for the observed property among observed dataset

The applied Principal Component Analysis (PCA) was further used to reduce 11-dimensional data (i.e. observed 11 properties) to 2 principal components: PC1 and PC2. In this case, the Principal Components (PCs) are new axes created by PCA that summarize the variability (differences) in the data. These axes are linear combinations of original variables. The PC1 the largest amount of variance (differences) in the data, while the PC2 captures the second-most variation in the data.

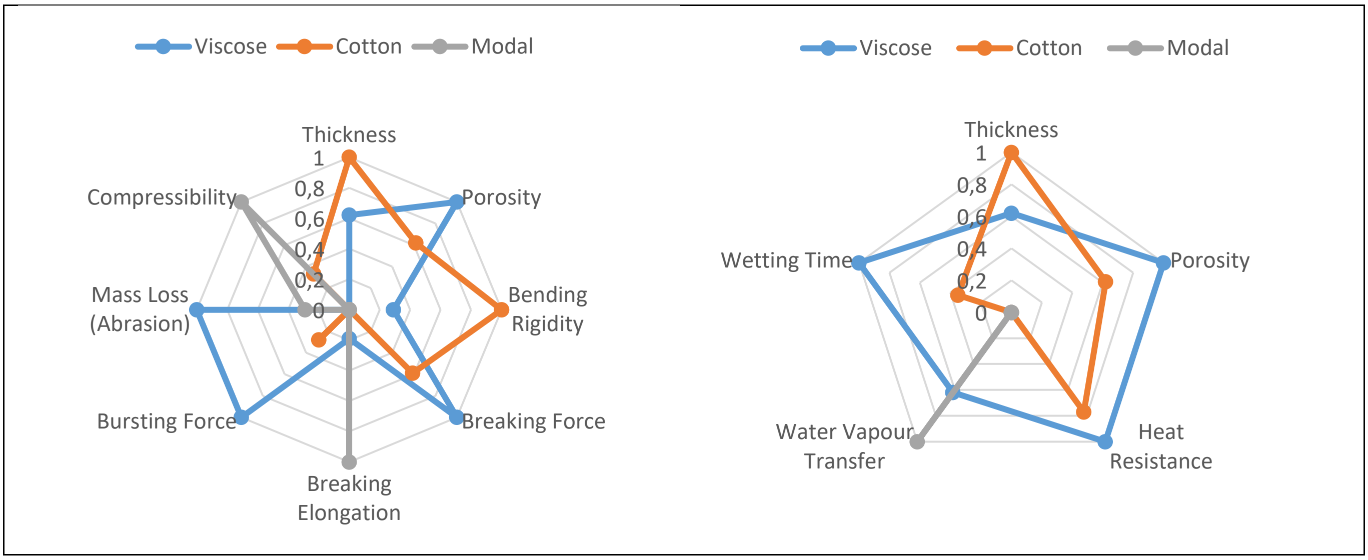
III. RESULTS AND DISCUSSION

In this chapter are shown the normalized values of the measured properties (Table 2), the plots of normalized values for two groups of properties, i.e. physical-mechanical properties, and the properties determing the thermophysiological comfort (Figure 1), and the results of the PCA analysis (Figure 2).

Table 2. The normalized values

Property	Viscose	Cotton	Modal
Thickness	0.62	**1.00**	0.00
Porosity	**1.00**	0.62	0.00
Bending Rigidity	0.29	**1.00**	0.00
Breaking Force	**1.00**	0.59	0.00
Breaking Elongation	0.19	0.00	**1.00**
Bursting Force	**1.00**	0.28	0.00
Mass Loss (Abrasion)	**1.00**	0.00	0.29
Compressibility	0.00	0.33	**1.00**
Heat Resistance	**1.00**	0.77	0.00
Water Vapour Transfer	0.62	0.00	**1.00**
Wetting Time	**1.00**	0.35	0.00

The normalized values of materials made of viscose, cotton, and modal yarns are provided in Table 2. Normalized values range from 0 to 1, where 1 indicates the best performance among the three for a given property, and 0 indicates the weakest. As can be seen, the normalized property values of viscose, cotton, and modal materials reveal distinct performance profiles for each yarn type. Viscose material demonstrates the strongest overall performance, achieving the highest values in key mechanical and functional properties such as porosity, breaking force, bursting force, heat resistance, and wetting time. This indicates that viscose-based fabrics may be structurally strong, and thermally stable, although they lack compressibility and elasticity. Cotton material, on the other hand, leads in bending rigidity, low mass loss due to abrasion, and maintaining moderate values across most other properties. However, it falls short in elasticity, and water vapour transfer. Modal material stands out for its comfort-related attributes, scoring highest in breaking elongation, compressibility, and water vapour transfer, which are desirable for softness, flexibility, and breathability. Despite these advantages, modal material scores lowest in all other mechanical and thermal categories, indicating limited durability and resistance. Overall, based on the results of this dataset, viscose material may be considered as more suitable for performance-demanding applications, cotton material for materials where the balanced properties are needed, while modal for comfort-driven textiles.



a. b.

Fig. 1 Plots of normalized values: a. Comparison of thickness and porosity with a range of physical-mechanical properties, b. Comparison of thickness and porosity with properties that determine thermophysiological comfort

Instead of comparing fibres across 11 properties, PCA analysis was used to compare all properties in just two dimensions (i.e. PC1 and PC2) that capture 100% of the variation in the observed dataset. The PC1 refers to the largest amount of variance (differences) in the data. As seen from Figure 2, for the observed dataset, it explains 71.5% of the variance in the dataset. The PC2 captures the second-most variation in the data, uncorrelated with PC1. As seen from the same figure, the PC2 for the observed dataset explains 28.5% of the variance.

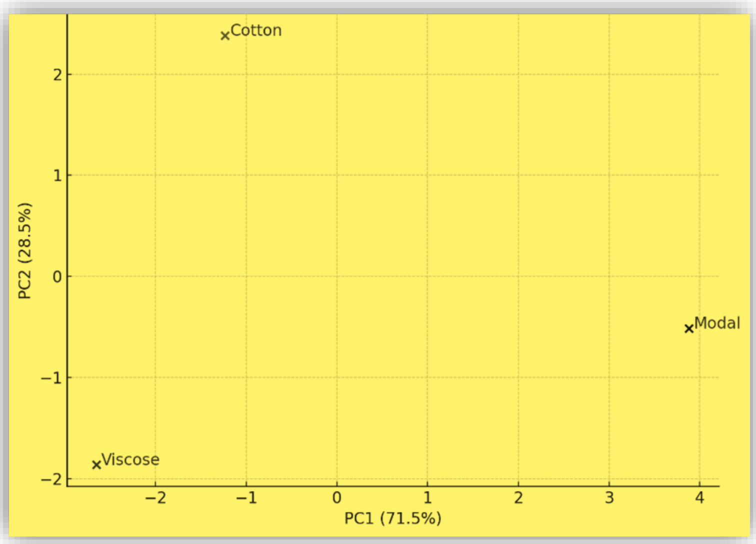


Fig. 2 The results of PCA analysis

When correlated directly with the types of yarns/fibres analysed, material made of viscose appears distinctly separated from both materials made of modal and cotton, particularly along the PC1 axis. This suggests that the material made of viscose yarn possesses notably different physical properties. The material made of modal yarn is clearly isolated along PC1 as well, highlighting its unique characteristics compared to the other materials. Finally, material made of cotton yarn occupies an intermediate position. As can be seen, it is closer to the material made of viscose on PC1, but shows separation along PC2, both for modal and viscose materials, due to differences in properties.

IV. CONCLUSION

The material selection is critical in sportswear, because the comfort, performance, and durability are key players. Within this research, the normalized values highlight the distinct strengths of each yarn type, with viscose excelling in mechanical and thermal performance, cotton offering balanced properties, and modal standing out in comfort-related features. These findings suggest that material selection should be guided by the specific performance or comfort requirements of the intended application. The PCA analysis further supported these insights by reducing the dataset to two components. According to the PCA analysis, the materials made of viscose and modal are clearly separated along PC1, reflecting their contrasting properties with the material produced of cotton that lies between them.

This study also pointed out the usefulness of the PCA analysis, as its outcomes may be further used by producers and designers to make better choices, matching fibre properties with functional needs like breathability, strength, and flexibility. Such approach leads to better, more targeted sportswear design and improved user experience.

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