

Exploring the potential of cellulosic fibre in activewear for sustainable fashion

Ritwick Halder¹, Abir Chakrabarti², Somes Bhaumik² & Sankar Roy Maulik^{1,a}

¹Department of Silpa-Sadana, Visva-Bharati (A Central University), Sriniketan 731 236, India

²Textile Research & Application Development Centre, Birla Cellulose, Kharach 394 120, India

Received 21 March 2024; revised received and accepted 29 September 2024

This study aims to evaluate the performance of regenerated cellulosic knitted fabrics in activewear applications, focusing on moisture management and thermal comfort. While sportswear and athleisure materials continue to evolve towards enhanced user comfort, polyester remains the dominant fibre in the activewear market due to its effective moisture transport capabilities. In contrast, this study develops and investigates single jersey fabrics made of 100 % dope-dyed viscose treated with a hydrophobic agent and viscose/excel blended yarns, comparing their performance with commercially available activewear. The results reveal considerable differences, highlighting the influence of fabric structure on wicking behaviour and heat flux values. Fabrics with greater air entrapment exhibit lower Q_{max} values, indicating reduced instantaneous cooling. The configuration of viscose/excel on the fabric face and hydrophobic finished viscose at the back demonstrates effective directional moisture transfer from the inner to the outer surface. The 100% regenerated cellulosic fabrics with a hydrophobic finish show significant differences in spreading speed between the face and back, enhancing moisture evaporation. The wicking behaviour and heat flux values are also influenced by the knitting structures, with regenerated cellulosic fabric with a hydrophobic finish showing higher Q_{max} values. The infra-red spectroscopic study helps to identify the hydrophobic component applied to viscose fibres. The findings support the potential of sustainable regenerated fibres as viable alternatives in moisture-regulating sportswear and performance textiles.

Keywords: Activewear, Dope dyed, Excel fibre, Hydrophobic finish, Moisture management, Viscose

1 Introduction

Clothing, following food, represents one of humanity's most essential needs, serving not only a protective function but also symbolising wealth, status, occupation, age, occasion, gender, etc.¹. The selection of clothing can be broadly classified into social, economic, environmental and physical factors. Among these, comfort remains paramount and can be categorised into thermo-physiological, sensory/tactile, mobility/dexterity, and psychological dimensions. Physiological indicators of comfort include skin temperature, degree of wetness, sweat rate and volume, sweat absorption by garments, and heart rate¹.

Thermo-physiological comfort refers to a fabric's ability to regulate heat and moisture between the body and the environment, influenced by properties like moisture management, breathability, thermal insulation, softness, etc. Tactile comfort depends on sensory responses to the fabric, while dexterity comfort is associated with freedom of movement and stretch, which is particularly important in activewear. Fabrics with elastane or lightweight

fibres such as silk or performance synthetics enhance this aspect².

Polyester dominates commodity and functional textiles, including activewear, due to its superior sweat-wicking, durability, and ease of care^{3,4}. However, its synthetic nature poses serious sustainability concerns—from non-biodegradability and microplastic pollution to complex recycling and environmental impact during production and use⁵⁻⁸. Polyester's hydrophobicity also limits comfort against the skin compared to natural fibres. Researchers are trying to use fibres from renewable resources, like cotton, bamboo, and lyocell, as possible substitutes for the synthetic materials often used in sportswear due to the growing demand for eco-friendly and sustainable textiles worldwide⁹. In recent times, knitted fabrics have gained popularity due to their easy production process, low cost, high level of garment comfort, etc.^{7,10}. With the growing demand for functional clothing, especially for active and ageing populations, attention is turning to alternatives that balance comfort, performance, and sustainability^{11,12}. Advanced activewear also incorporates technologies like stimuli-responsive polymers (SRPs) and phase change materials (PCMs) to address moisture transport limitations¹³.

¹Corresponding author.
E-mail: s_r_moulik@yahoo.co.in

Activewear is a key segment of functional textiles, offering moisture transport, fast drying, and enhanced comfort during physical activity¹⁴. Nowadays, sportswear brands are concerned with sustainability while developing new materials to meet performance and aesthetics. The brands now take care of the Triple Bottom Line (TBL) of sustainability, which relates to people, the planet and profit¹⁵. More people's participation in sports and leisure activities, resulting in the growth of the sportswear sector, leads to unsustainable consumption of resources to meet the increasing demand. In addition to fibre properties, fabric structure, comfort, etc., are also explored by several researchers for designing future sportswear and activewear using sustainable materials and emerging technologies^{16,17}.

Bio-based fibres such as polylactic acid (PLA) and regenerated cellulose are increasingly adopted in sports textiles due to their biodegradability and low environmental impact, aligning with global sustainability goals. Researchers emphasise the integration of sustainable materials with high-performance functionalities—such as breathability, UV protection, and antibacterial properties, as a key trend in the next generation of eco-functional sportswear¹⁸. Natural protein-based luxury textiles, such as silk and wool, demonstrated higher biodegradability, highlighting their potential for zero-waste luxury fashion. The study reported that luxury fabrics treated with plant-based finishes showed a 40–60 % faster degradation rate within 90 days without compromising tactile properties¹⁹.

Cellulosic fibres are naturally hydrophilic, enabling rapid absorption, while viscose's nanoporous structure enhances its moisture uptake. On the other hand, polyester relies on its hydrophobic, non-absorbent surface to wick moisture, though it lacks the softness of natural fibres.

Regenerated cellulosic fibres, manufactured from cellulose extracted from wood pulp, like viscose, modal and lyocell, are breathable, soft and biodegradable. They

offer an environmentally preferable alternative to synthetics and are widely used in apparel, home, and industrial textiles.

Wicking fabrics either use capillary-based synthetic fibres (e.g. COOLMAX of DUPONT, COOLPLUS of Taiwan, China) or are engineered for moisture movement. These synthetic fibres can suffer performance loss due to blocked grooves and show drawbacks such as excessive hairiness, colour fading, and reduced post-wash functionality²⁰. Cellulosic fibres, while comfortable, may underperform in moisture management and durability²¹. Researchers have attempted to improve these aspects via blending, surface treatments, and finishes²². Despite such efforts, there is a growing need for environmentally friendly sportswear that combines performance with sustainability.

Given the points discussed above, this study aims to develop environmentally responsible cellulosic knitted sportswear with a hydrophobic back and compare its various functional properties, such as absorption rate, spreading speed, air permeability, heat flux and wicking properties, with the commercially available polyester blended knitted products.

2 Materials and Methods

2.1 Materials

Table 1 shows different yarns used individually or in combination to produce knitted structures. Modal, viscose and excel fibres were obtained from Birla Cellulose, Aditya Birla Group, and all were dope dyed. The developed fabric (S6) was tested and compared against commercially available samples (S1 to S5).

Dope-dyed viscose, or spun-dyed viscose, is coloured during fibre production, offering superior colour fastness, reduced water and chemical consumption, and greater manufacturing efficiency. This method ensures uniform dye distribution, improves UV resistance, and allows for

Table 1 — Yarn types and structural parameters of knitted fabrics

| Sample | Yarn details | Knitted structure | Wales/inch, WPI | Course/inch, CPI | Areal density, GSM |
|--------|---|-------------------|--------------------|---------------------|-----------------------|
| S1 | 50 Ne cotton (Face) + 75 D Polyester (Back) | Single Jersey | 60 | 80 | 148 |
| S2 | 30 Ne Birla Modal 100% | Single Jersey | 46 | 44 | 135 |
| S3 | 150 D Polyester 100% | Single Jersey | 48 | 56 | 150 |
| S4 | 60 Ne Modal (Back) + 100 D Polyester (Face) | Plated Structure | 38 | 48 | 180 |
| S5 | 60 Ne Excel (Back) + 100 D Polyester (Face) | Plated Structure | 38 | 46 | 170 |
| S6 | 60 Ne Viscose/Excel (Face) + 40 Ne Viscose (Hydrophobic) (Back) | Single Jersey | 40 | 44 | 143 |

colour customisation. Integrating dye during spinning enhances fabric durability and contributes to sustainable processing.

2.2 Methods

Single jersey fabrics of 100 % Birla modal (S2), 100 % polyester (S3) and 100 % regenerated cellulosic with a hydrophobic finish at one side (S6), along with the plated fabric of polymodal (S4) and polyester/excel (S5) were produced and tested along with commercial sample made of polyester/cotton (S1). All testing was conducted in a controlled atmosphere (21 ± 1 °C, 65 ± 2 % RH). The moisture management properties of all six fabrics were tested and evaluated by using the Moisture Management Tester (MMT), and the feeling of coldness or warmth was assessed by measuring the ' Q_{\max} ' value (peak heat flux) on KES-F7 ThermoLabo II.

2.2.1 Hydrophobic Finish to 100 % Viscose Yarn

40 Ne dope dyed 100 % viscose yarn was treated with the hydrophobic finish of commercial grade and green acid for 20 min at 40 °C in a yarn dyeing machine of five-kilogram capacity. Wetting agents and defoamers were also added during the process. After the hydrophobic finish, the cones were dried in the hydro-extractor, followed by the radio frequency dryer. This yarn was used to create the hydrophobic surface.

2.2.2 Knitting Process

Two knitting structures — single jersey and plated double jersey — were used. The present study developed a single jersey structure on a circular weft knitting machine of Mayer & Cie, Model S4-3.2, Germany. In plated fabrics, two different yarns are fed simultaneously, predominantly on the face and the other on the back. The polyester yarn was used on the face, and modal/excel was used on the back for enhanced comfort and durability. Plated structures were also knitted using the Mayer & Cie S4-3.2 machine.

2.2.3 Determination of Wales/inch, Course/inch and Areal Density

In knitted structures, wales per inch (WPI) and courses per inch (CPI) were determined following IS 1963-1981. Areal density (GSM) was measured following IS 1964-2001. All values represent the average of ten readings.

2.2.4 Moisture Management Properties

Moisture management tests, including absorption rate and spreading speed (face and back), were

measured using the Moisture Management Tester (MMT), developed by SDL Atlas, to evaluate textile moisture management properties.

2.2.5 Air Permeability

Air permeability was assessed according to ASTM D737 using the SDL Atlas Air Permeability Tester to determine the breathability of the fabrics.

2.2.6 Heat Flux (Q_{\max})

The peak heat flux (Q_{\max}), indicating the sensation of coolness or warmth, was measured using the KES-F7 ThermoLabo II. Higher Q_{\max} values correlate with greater heat conduction and a cooler feel on skin contact.

2.2.7 Wicking Height

Vertical wicking behaviour was evaluated by AATCC 197. The wicking height represents the distance water travels through capillary action, indicating the fabric's moisture transport efficiency.

2.2.8 Microscopic Test

The yarn samples were subjected to the microscope before and after applying the finish to examine the changes, if any, in the cellular structure of the yarns. The yarn was cut along its cross-section and placed on the mount of a digital trinocular research microscope at magnification $\times 40$.

2.2.9 FTIR Spectroscopy

FTIR spectra of excel fibre, excel/viscose blended fibre, and viscose fibre treated with a hydrophobic finishing agent were recorded using the ATR-IR spectroscopy, Shimadzu, Japan, at a resolution of 8.0 cm^{-1} with a scanning range of 400 - 4000 cm^{-1} . The total number of scans was 45 during the test.

3 Results and Discussions

3.1 Moisture Management Properties

Table 2 summarises the moisture management and physical properties of all six knitted fabric samples used in this study. Figure 1 shows the single jersey knitted structure developed using viscose/excel on the face side and viscose with a hydrophobic finish on the back (S6).

3.1.1 Absorption Rate

The absorption rate refers to the average rate at which a fabric absorbs water droplets upon initial contact. It reflects the fabric's ability to permit moisture penetration through inter-yarn, inter-fibre, and intra-fibre spaces. Table 2 shows the average

Table 2 — Moisture management and physical properties of various knitted structures

| Sample | Weight, g/m ² | Absorption rate, %/s | | Spreading speed, mm/s | | Air permeability, l/m ² /s | Q _{max} | Wicking height (cm) at 10 min |
|--------|--------------------------|----------------------|-------|-----------------------|------|---------------------------------------|------------------|-------------------------------|
| | | Face | Back | Face | Back | | | |
| S1 | 148 | 36.90 | 57.50 | 3.94 | 3.93 | 1863 | 890 | 12.7 |
| S2 | 135 | 50.30 | 43.20 | 4.53 | 4.49 | 2704 | 1024 | 8.4 |
| S3 | 150 | 49.00 | 40.50 | 6.12 | 6.75 | 1964 | 904 | 10.0 |
| S4 | 180 | 52.50 | 40.30 | 3.45 | 3.23 | 497 | 955 | 8.5 |
| S5 | 170 | 52.75 | 40.85 | 4.01 | 3.89 | 484 | 970 | 8.9 |
| S6 | 143 | 21.98 | 11.50 | 0.67 | 0.35 | 2790 | 1034 | 6.4 |



Fig. 1 — Single jersey knitted structure

absorption rates of each knitted structure's face and back surfaces. The fabrics with 100 % modal (S2) and 100 % polyester (S3) exhibit comparatively lower differences in absorption rates between the two surfaces, attributable to the use of uniform fibre compositions and identical structures. Similar trends are observed in S4 (modal/polyester) and S5 (excel/polyester), where plated constructions minimise inter-surface variability.

Conversely, the commercial reference (S1) displays a relatively higher difference in absorption rate between the face and the back, likely due to its mixed fibre composition (cotton and polyester). S6, with a hydrophobic finish applied to the back, demonstrates the most significant inter-surface difference. The hydrophobic surface effectively repels water, directing moisture towards the hydrophilic outer face. Consequently, both surfaces of S6 absorb less water overall, owing to the combined effects of fibre composition, surface modification and knitted structure.

3.1.2 Spreading Speed

As shown in Table 2, the spreading speed measures how quickly absorbed moisture spreads across the fabric surface. Samples S1-S5 show negligible differences in spreading speed between the face and back layer, indicating relatively uniform spreading characteristics. However, the 100 % cellulosic sample with a hydrophobic finish (S6) shows a significant

difference, with the face side exhibiting almost double the spreading speed compared to the back. This can be attributed to the hydrophobic treatment on the back, which restricts moisture absorption and encourages directional moisture movement to the face. This behaviour facilitates more efficient evaporation, enhancing wearer comfort.

3.1.3 Air Permeability

Air permeability measures the ease of airflow through a fabric and is critical for breathability. As presented in Table 2, S6 exhibits the highest air permeability, followed by S2, S3, and the commercial sample S1. Fabrics with plated structures (S4 and S5) demonstrate comparatively lower permeability. The single jersey structure of S6, combined with its cellulosic fibre content, results in greater porosity and, hence, enhanced breathability. This confirms the strong influence of both structure and material composition on air permeability.

3.1.4 Peak Heat Flux

Q_{max} represents the peak rate of heat transfer from the skin to the fabric, indicating thermal sensation (coolness or warmth). Higher Q_{max} values correspond to cooler sensations upon contact. It is calculated as the maximal heat transfer rate (Watt/m²) between the body and the fabric. As the value increases, the wearer feels colder. On the Kawabata System, Q_{max} is the maximum value of heat current that can flow through the fabric as soon as the heat generated from the pure copper plate has reached the fabric's surface. It mimics the temporary heat transfer (warm/cold sensation) that occurs when a human finger touches an object. As shown in Table 2, S6 and S2 (made from regenerated cellulosic fibres) exhibit higher Q_{max} values, indicating a cooler touch than polyester-rich samples (S1, S3, S4, and S5). Polyester's inherently lower thermal conductivity contributes to reduced Q_{max} values. The hydrophilic character of regenerated cellulose enhances heat transfer, positioning S6 as thermally more comfortable.

3.1.5 Wicking Properties

Wicking height indicates the vertical transport capability of liquid through the fabric. Table 2 reveals that the commercial sample (S1), containing hydrophobic polyester yarns, displays the highest wicking height due to superior capillary action. The wicking properties of a fabric mainly depend on the fibre used and the fabric structure. The commercial sample has 75D polyester on the back surface. Polyester is completely hydrophobic and thus shows the best capillary action. However, the sample with a hydrophobic finish on the back side (S6) shows a much lower wicking height. This is likely due to its hydrophilic core limiting rapid vertical movement and the applied finish primarily affecting surface-level moisture transfer.

3.1.6 Microscopic Analysis

Microscopic examination of the yarns before and after hydrophobic treatment (Fig. 2) reveals no significant disruption to the fibre's internal structure. The finish appears to coat the surface without altering the core cellular morphology, confirming that the treatment affects only the surface of the yarns.

3.1.7 FTIR Analysis

Figure 3 shows the FTIR spectra of (a) excel, (b) viscose/excel blend and (c) viscose yarn treated with a hydrophobic finish. FT-IR spectra at absorption bands of 3323 cm^{-1} , 3336 cm^{-1} , and 3325 cm^{-1} , noticed for all samples, are due to the stretching of O-H groups. Aromatic C-H stretching vibrations are observed in the $1560\text{--}1300\text{ cm}^{-1}$ region for all samples. The presence of bands at 1155 cm^{-1} and 1020 cm^{-1} is due to C-O stretching vibrations²³⁻²⁴. A broad absorption band at 2891 cm^{-1} for both 3a and 3b is due to C-H stretching vibrations²⁵. Viscose treated with a hydrophobic finish, i.e. sample 3c, a broken hump at that region might suggest that the C-H stretching

vibrations are affected by weak hydrogen bonds or lower bond enthalpies with others²⁶. There is a variation in peak height near the absorption band of 2891 cm^{-1} for the samples without a hydrophobic finish compared to samples with a hydrophobic finish. This indicates the presence of more hydrogen bonds in samples A and B compared to C²⁷. A clear absorption band at a wave number of 1236 cm^{-1} is noticed in the sample treated with a hydrophobic finish (C), which is absent for samples A and B. This peak may be due to an epoxy group corresponding to an asymmetrical aromatic C-O stretching or OH/NH stretching for amino dimethyl silicone.

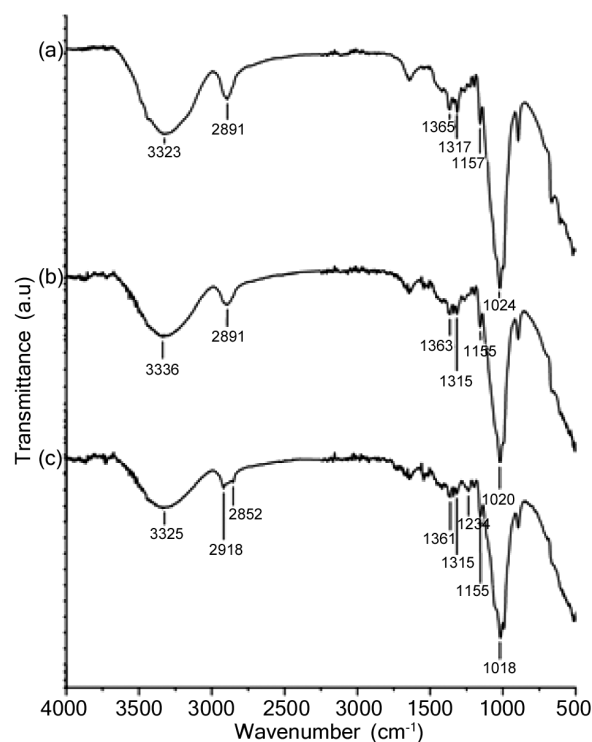


Fig. 3 — FTIR spectra (a) excel fibre, (b) viscose/excel and (c) viscose with hydrophobic finish

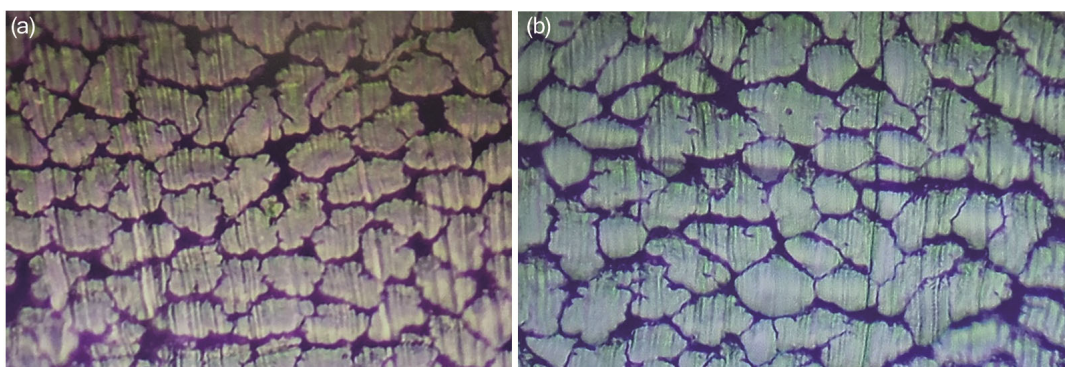


Fig. 2 — Cross-sectional views of yarns (a) before and (b) after hydrophobic finish

4 Conclusion

This study demonstrates that regenerated cellulosic knitted fabrics, particularly those developed using viscose/excel on the face and hydrophobically finished viscose on the back (S6), offer promising potential as sustainable alternatives to polyester-based activewear. The fabric exhibits superior air permeability and higher Q_{\max} values, indicating improved breathability and a cooler feel against the skin. The distinct difference in absorption rate and spreading speed between the face and back surfaces confirms directional moisture transfer, enhancing wearer comfort. While the wicking height of the hydrophobically finished sample (S6) is lower than that of polyester-rich commercial samples, its capacity to transfer moisture from the skin-facing side to the outer surface through structural and surface modification is noteworthy. Microscopic and FTIR analyses confirm the surface-level modification without compromising the internal fibre structure, validating the application of the hydrophobic finish. The findings suggest that cellulosic fabrics with hydrophobic treatment can achieve performance characteristics comparable to synthetic activewear while offering enhanced sustainability.

Acknowledgement

The authors would like to acknowledge Dr. Mahasweta Nandi, Assistant Professor, and Mr. Prasanta Pal, Research Scholar of the Integrated Science Education and Research Centre, Visva-Bharati University, for their help during the FTIR testing.

References

- Das A & Alagirusamy R, Science in Clothing Comfort, (Woodhead Publishing India Pvt. Ltd., New Delhi), (2010).
- Honade B S, Shrivastava N, Behera J, Ramakrishnan V, Dayal A & Jadhav G, *Indian J Fiber Text Res*, 44(1) (2019) 24.
- Júnior H L O, Neves R M, Monticeli F M & Dall A L, *Textiles*, 2 (2022) 582, <https://doi.org/10.3390/textiles2040034>.
- Devanand U, *Int J Eng Appl Sci Res*, 2 (1) (2013) 34.
- Palacios-Mateo C, van-der Meer Y & Seide G, *Environ Sci Eur*, 33 (2) (2021), doi: 10.1186/s12302-020-00447-x.
- Patel M K & Leal F W, *J Clean Prod*, 91 (2016) 65.
- Wright T, Mahmud-Ali A & Bechtold T, *J Clean Prod*, 275 (2020) 123857.
- Akbarpour H, Rashidi A, Mirjalili M & Nazari A, *J Nanostructure Chem*, 9 (2019) 335.
- Wang Y, Postle R & Kessler R, *J Text Appar Technol Manag*, 8 (4) (2013) 1.
- Ray S C, Fundamentals and Advances in Knitting Technology, (Woodhead Publishing India Pvt. Ltd., New Delhi), (2012).
- McCann J, *Fashion Pract*, 8(2) (2016) 234, doi.org/10.1080/17569370.2016.1215118.
- Liu R, Fung E & Abida Y, Evaluation of Perceived Comfort and Functional Performance of Activewear, Editor: Yip J, In: The Textile Institute Book Series, Latest Material and Technological Developments for Activewear, (Woodhead Publishing), (2020) 89, doi.org/10.1016/B978-0-12-819492-8.00005-3.
- Govindan N, *J Text Appar Technol Manag*, 10 (3) (2018) 1.
- Bandanova A, Taussarova B & Kutzhanova A, *World Appl Sci J*, 30 (10) (2014) 1409.
- Nayak R Sportswear and Activewear: Analysis of Recent Trends from a Sustainability Standpoint, Editor: Nayak R, In: The Textile Institute Book Series, Sustainable Sportswear and Activewear, Elsevier, (2025) 1, doi.org/10.1016/B978-0-443-18872-5.00011-8.
- Maduna L, Patnaik A & Isaacs S, Future Directions in Sustainable Design of Sportswear and Activewear, Editor: Nayak R, In: The Textile Institute Book Series, Sustainable Sportswear and Activewear, Elsevier, (2025) 283, doi.org/10.1016/B978-0-443-18872-5.00008-8.
- Dhir Y J, Diverse Sustainable Aspects in Sportswear Design and Development, Editor: Nayak R, In: The Textile Institute Book Series, Sustainable Sportswear and Activewear, Elsevier, (2025) 133, doi.org/10.1016/B978-0-443-18872-5.00004-0.
- Cui G & Wang C, *Alex Eng J*, 126 (2025) 491, doi: 10.1016/j.aej.2025.04.094.
- Jaisri J & Balaji S, Biodegradable Elegance: Assessing Luxury Textile Biodegradability, in Crafting Sustainability in Luxury Textiles for a Zero-Waste Future, Editor: Sadhna, Kumar R & Mokanaasri E (Springer, Cham), (2025) 43, doi: 10.1007/978-3-031-86773-6_5.
- Ramratan R & Choudhary A, *J Text Appar Technol Manag*, 11 (2) (2020), doi.org/10.1007/s40034-020-00157-2.
- Cai Z, Liu Z & Yan C, *J Mater Sci Res*, 3 (2) (2014) 56.
- Singh A, Mehta V & Kumar P, *J Text Res Appl*, 15 (2) (2023) 101.
- Shabbir M, Islam S, Bukhari M, Rather L, Khan M & Mohammad F, *Text Cloth Sustain*, 2 (2017), doi:https://doi.org/10.1186/s40689-016-0011-8.
- Yaneva Z, Ivanova D, Beev G & Besheva K, *Bulg Chem Commun*, 52 (2020) 41.
- Sun J X, Sun X F, Zhao H & Sun R C, *Polym Degrad Stab*, 84 (2004) 331.
- Miyazawa T & Shimanouchi T, *J Chem Phys*, 29 (4) (1958) 611.
- Sao P K & Jain K A, *Indian J Fiber Text Res*, 20 (1995) 185.