EFFECT OF FABRIC STRUCTURE ON THE AIRPERMEABILITY AND MOISTURE MANAGEMNT OF THE SOCKS MADE OF COTTON, COTTON/BAMBOO AND COTTON/BANANA YARNS

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Abstract: This study examines the impact of fabric structure on the air permeability characteristics of socks knitted from three different yarn compositions: 100% cotton, cotton/bamboo blend, and cotton/banana blend. Two distinct knit structures—single jersey and rib were employed to assess the combined effect of fiber content and fabric architecture on breathability. Air permeability measurements were conducted under standardized conditions using a digital air permeability tester. The results indicate that both yarn composition and fabric structure significantly influence the air permeability of the socks. Among the fabric types, rib structures consistently exhibited the highest air permeability, followed by single jersey construction. Furthermore, socks made from cotton/bamboo and cotton/banana yarns demonstrated enhanced air permeability compared to those made from pure cotton, attributed to the more porous and hydrophilic nature of bamboo and banana fibers. These findings underscore the importance of selecting appropriate fiber blends and fabric structures to optimize the comfort and functional performance of socks, particularly in applications requiring effective moisture management and ventilation.

Key Words: Socks, Cotton, Bamboo, Banana, Knit structure, Air permeability and Moisture management properties

Introduction

Air permeability is a critical parameter in evaluating the comfort of hosiery. It governs thermal regulation and moisture management, both essential for foot health and wearer satisfaction[18]. Fabric structure and fiber content are recognized as major influencers of airflow through textiles[21].

Cotton is a widely utilized natural fiber prized for its softness and moisture absorption, though its compact fiber arrangement can reduce airflow. In contrast, regenerated bamboo fibers—with greater porosity—enhance both air and moisture permeability in knitted constructions[18].

Cotton/bamboo blends have been particularly well studied. An 83:17 bamboo blend exhibited the highest air and water-vapor permeability among tested samples, using circular-knitted fabrics. Similarly, [9]analysed 50:50 blends in rotor-spun yarns used in single-jersey knits—finding comparable air-permeability and comfort to 100% bamboo fabrics.

Alternative fibers like banana are gaining attention for their unique morphological traits—large diameter and stiffness—that can improve porosity and breathability in blended textiles[11]. Fabric knit structure also plays a pivotal role. Plain, rib, and interlock constructions differ in loop configuration, thickness, and porosity—all affecting air permeability[18]. [9]Similarly observed increased permeability with higher bamboo content and looser knit structures in single-jersey fabrics. Natural fiber is used as an alternative resource to synthetic fibres as well as reinforcement for polymer composite materials and the manufacturing is inexpensive, renewable and environment friendly[22]. The increase in body temperature increases the sweat rate. Generally, sweat begins to discharge the cooling arrangement of the body to eliminate surplus heat created in the body. At the point when the perspiration dissipates from the skin or fabric texture surface, water vapour conveys this excess heat, as a result of which, the comfort status of the body is secured [15-20].

Maintaining a stable microclimate between the skin and surrounding textiles depends on the textile's thermo-physiological properties. The main parameters for the objective evaluation of thermo-physiological comfort properties in socks are heat transfer resistance (thermal resistance) and moisture management[23,24].

The thermal resistance of fibres depends on their ability to conduct heat and heat loss through a textile structure and relates mainly to the thermal conductivity of the fibrous matter, the thickness of the fabric, and its porosity[1,2]. According to the results we concluded that including yarn and socks parameters i.e. TPI and extension [mm] significantly influence overall moisture management and accumulative one-way transport index values of plated socks samples[12].

The moisture management properties of socks made from recycled polyester, virgin cotton and its blends were studied and compared. As an outcome of this research, the OMMC (Overall Moisture Management Capacity) of socks produced from recycled polyester fabrics gave higher values than those of virgin cotton fabrics[25].

Although extensive research has been conducted on woven fabrics and general knitted structures, studies specifically addressing sock-specific fabric constructions made from cotton/bamboo and cotton/banana yarns are notably limited. Existing literature predominantly concentrates on plain knits or woven materials, offering little insight into the nuanced performance of hosiery fabrics[26]. In particular, comparative analyses of single jersey and rib structures within socks composed of these sustainable fiber blends are scarce. This gap underscores the need for focused research to better understand how fiber composition and knit architecture interact to influence the functional properties of sock fabrics[7,8,10].

Compared to other textiles, socks are made at the lowest cost and have the highest consumption rate, making them one of the least-lasting fabric goods in the clothing industry[4-6]. The fact that socks and shoes have fewer air circulation options than other areas of the body means that they must be more comfortable than any other item of clothing. Water-vapor transport or the capacity of textile materials to enhance evaporation are key factors in the comfort of textile materials[3,27,28].Many studies are there about construction and performance characteristics of fabrics and their assessment how the comfort properties and comfort levels can be imparted or achieved. Most of them emphasized over blends of conventional cellulosic materials like cotton, wool, regenerated materials i.e. rayon & bamboo and synthetic materials i.e. polyester & aramid fabric materials but not purely te synthetic materials along with the core of polyurethane as elastomeric yarn. Out of already worked materials, 100% cotton and polyester is top of the list[12-22].

Material and Methods

The socks were manufactured using yarns with a count of 30s Ne, selected for their fine texture, which is ideal for producing lightweight, comfortable, and durable hosiery. Three yarn compositions were utilized: 100% cotton, a 60% cotton / 40% bamboo blend, and a 60% cotton / 40% banana fiber blend. The 100% cotton yarn offers inherent softness, breathability, and effective moisture absorption. The blended yarns combine the natural comfort of cotton with the functional enhancements of bamboo and banana fibers, including improved moisture management, antibacterial properties, superior air permeability, and environmental sustainability. These material combinations were chosen to enhance the overall comfort, performance, and ecological profile of the socks.

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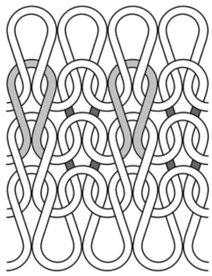


Single Jersey 1 x 1 Rib

Figure 1: Knitted structures of Socks produced

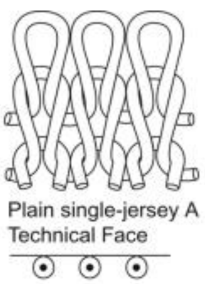
The single jersey socks were produced using the Onati G 614, a high-performance knitting machine manufactured in Italy in 2004. This advanced single-cylinder model is equipped with 200 needles and a 3¾-inch diameter cylinder, enabling precise and efficient knitting. Operating at a 22-gauge setting, the machine delivers fine, uniform stitches, making it particularly suitable for crafting soft, durable, and comfortable socks. Its robust design supports the production of both basic and intricately patterned socks with consistent fabric density and high-quality stitch formation. The Onati G 614's technical capabilities make it an ideal choice for manufacturing premium hosiery with excellent comfort and structural integrity.

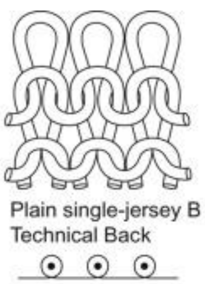
The 1×1 rib socks were manufactured using the BS BOO Seong Precision knitting machine, a technologically advanced model built in 2002. Equipped with 168 needles and a 5-feeder system, this machine offers exceptional versatility in design, allowing for the production of a wide range of sock patterns. With a 13.5-gauge setting and a 4-inch cylinder diameter, it produces high-density, durable knitted fabrics that strike an optimal balance between comfort and longevity. Operating at speeds between 180 and 300 RPM, the machine ensures efficient, high-volume production without compromising stitch consistency or quality. The BS BOO Seong Precision machine is well-suited for both basic and complex sock designs, making it a reliable choice for large-scale, high-quality sock manufacturing.

Experimental Method

S.No	**Sample**	**Fibre Type**	**Structure**
1	CSJ	100 % Cotton	Single Jersey
2	CRB	100 % Cotton	1 x 1 Rib
3	BMCSJ	40 % Bamboo / 60 % Cotton	Single Jersey
4	BMCRB	40 % Bamboo / 60 % Cotton	1 x 1 Rib
5	BNCSJ	40 % Banana / 60 % Cotton	Single Jersey
6	BNCRB	40 % Banana / 60 % Cotton	1 x 1 Rib

Table 1: Technical specifications of socks





- ∗ CSJ : Cotton Single Jersey Socks
- ∗ CRB : Cotton Rib Socks
- ∗ BMCSJ : Bamboo/Cotton Single Jersey Socks
- ∗ BMCRB : Bamboo/Cotton Rib Socks
- ∗ BNCSJ : Banana/Cotton Single Jersey Socks
- ∗ BNCRB : Banana/Cotton Rib Socks

The produced socks were tested according to the standard procedure for evaluating their physical and structural properties, such as loop length (ASTM D 3887), and GSM. A summary of the physical and structural properties assessed for the fabrics is provided in Table.

Air Permeability Properties

The air permeability of the produced socks was assessed in accordance with IS 1058:1984 using a DIN 55387 standard air permeability tester. This test evaluates the rate at which air passes perpendicularly through the fabric under a specified pressure difference, which is essential for determining the breathability and comfort of the socks. Prior to testing, fabric samples were conditioned under standard atmospheric conditions (20$\pm$ 2°C and 65$\pm$ 2$^{\%}$ relative humidity) for at least 24 hours. Swatches from the socks were then cut and mounted securely in the test head of the air permeability tester, ensuring no air leakage and no fabric distortion. A constant pressure differential, typically 100PA, was applied and the instrument measured the volume of the air passing through a defined area of the fabric over time, with results expresses in units such as $cm^3/cm^2/s$ or $I/m^2/s$. multiple readings were taken across different sections of each sample to ensure accuracy and the average air permeability was calculated. This test provides valuable insight into the fabric's ability to allow air circulation, which directly influences the overall thermal comfort and performance of the socks.

Moisture Management

A moisture management capability assessment was performed on fabric sample A1 utilizing the SDL Atlas Moisture Management Tester to determine the fabric's efficiency in handling liquid moisture under controlled laboratory conditions. The objective of the test was to evaluate the fabrics capacity for moisture absorption, distribution and transport, which are essential characteristics for performance textiles such as sportswear and functional apparel. The test was conducted using a fabric specimen weighing 10.000 grams, with environmental conditions maintained at 22°C and 70% relative humidity to ensure test conditions and reliability. Moisture was introduced to the fabric via a 20 second pump cycle and the fabric's response was monitored over a 120 second evaluation period. This procedure enables the analysis of critical performance metrics including absorption rate, wetting behaviour, spreading speed and directional moisture transport from the inner to the outer surface. These parameters collectively reflect the fabric's ability to manage perspiration effectively, contributing to enhanced wearer comfort and optimal thermo physiological performance.

Results and Discussion

Physical Properties of the Socks

S.No	Name of the Socks	CPI	WPI	SD	Thickness	Loop Length (mm)	GSM (gm)	Fabric Density (g/cm^2)
1	CSJ	38	31	1392	0.6	0.33	2.19	0.0365
2	CRB	30	22	816	1.1	1.16	2.4	0.0267
3	BMCSJ	38	32	1178	0.7	0.33	1.36	0.0194

4	BMCRB	34	23	782	1.0	1.18	3.57	0.0357
5	BNCSJ	40	31	1240	0.6	0.34	1.84	0.0307
6	BNCRB	34	21	714	1.2	1.16	4.19	0.0349

Table 2: Physical Properties of socks produced

The structural and physical characteristics of six socks variants – CSJ, CRB, BMCSJ, BMCRB, BNCSJ and BNCRB were meticulously analyzed to evaluate their fabric integrity and functional performance. BNCSJ recorded the highest courses per inch at 40, indicating a finer vertical knit structure, while CRB and BNCRB exhibited the lowest values (30 and 34 respectively), suggesting a relatively coarse construction. Among the samples, CSJ demonstrated the highest stitch density (1392), reflecting a tightly knit and a compact fabric, whereas BNCRB showed the lowest stitch density (714), implying a more open structure. Thickness measurements revealed that BNCRB (1.2mm) and CRB (1.1mm) were the most substantial, providing enhanced cushioning and insulation, whereas CSJ and BNCSJ (0.6mm) were the thinnest, likely contributing to improved breathability. Loop length was greatest in BNCRB and CRB (1.16mm), indicative of greater yarn consumption and potentially enhanced softness, while CSJ and BMCSJ (0.33mm) featured the shortest loops, pointing to a tighter knit. In terms of fabric mass, BNCRB exhibited the highest GSM (4.19gm), denoting a heavier and denser fabric, while BMCSJ had the lowest GSM (1.36gm), reflecting a lightweight composition. Fabric density was most pronounced in CSJ (0.0365g/cm^2), implying a compact and durable textile, while BMCSJ recorded the lowest density (0.0194 g/cm^2). Porosity values, which denote the material's air permeability, were highest in BMCSJ (98.74%), suggesting superior breathability and lowest in CSJ (97.63%), indicating a more restrictive air flow. Overall, BNCRB emerged as the thickest, heaviest and most robust sample, suitable for enhanced warmth and durability, whereas BMCSJ stood out for its lightweight nature and excellent breathability, making ideal for comfort-focused applications.

Air Permeability of the Socks

Air permeability testing was carried out on six fabric samples following the Indian Standard IS: 11056-1984, suing a test area of 125x125 cm. this test determines how easily air can pass through a fabric, measured in cc/sec/cm^2. Highest values indicate that the fabric is more breathable or porous, while lower values suggest a tighter weave or denser construction that restricts airflow.

Before analyzing the test results, it's important to note that air permeability is influenced by several factors, including yarn type, fabric structure, thickness and any chemical or mechanical treatments applied. Therefore, variations in permeability across different samples are expected and can significantly impact the fabric's suitability for applications requiring breathability or air resistance.

S.No	Sample	cc/sec/cm^2
1	CSJ	45.39
2	CRB	42.75
3	BMCSJ	51.50
4	BMCRB	45.28
5	BNCSJ	40.72
6	BNCRB	43.89

Table 3: Air Permeability of socks produced

Among the six samples tested, BMCSJ showed the highest air permeability at 51.50 cc/sec/cm^2, indicating a more open or loosely structures fabric. On the other hand, BNCSJ recorded the lowest permeability at 40.72 cc/sec/cm^2, suggesting a tighter knit or higher fabric density. The control samples, CSJ and CR had permeability values of 45.39 and 42.75 cc/sec/cm^2, respectively. Treated variants like BMCRB and BNCRB showed intermediate values of 45.28 and 43.89 cc/sec/cm^2.

When comparing treatments, fabrics treated with BMCSJ and BMCRB generally showed higher air permeability than those treated with BNCSJ and BNCRB, implying that the BMCSJ and BMCRB treatment may enhance fabric porosity. Additionally, CSJ samples consistently demonstrated slightly higher permeability than CRB counterparts, regardless of treatment. These findings emphasize how both fabric type and finishing processes influence air permeability, which in turn affects fabric performance in practical use.

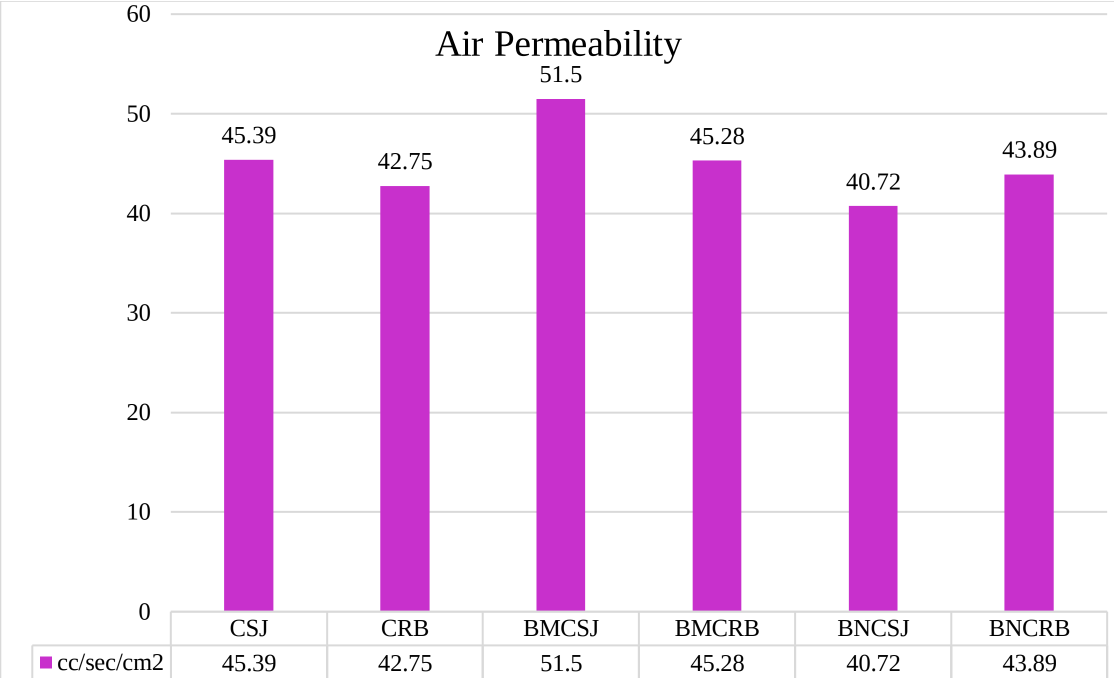


Figure 2: Air Permeability of Socks produced

Fabric Porosity

S.No	Name of the Socks	Porosity%
1	CSJ	97.63
2	CRB	98.27
3	BMCSJ	98.74
4	BMCRB	97.68
5	BNCSJ	98.01
6	BNCRB	97.73

Table 4: Porosity of socks produced

The porosity analysis of the socks samples demonstrates the significant influence of both fibre composition and knit structure on air permeability and overall comfort. The BMCSJ sample recorded the highest porosity at 98.74%, indicating excellent breathability. This likely due to the inherent moisture-wicking and hollow properties of bamboo fibres, combined with the open nature of the single jersey knit. The CRB sample showed a slightly lower porosity 98.27%, suggesting that while rib knits are typically denser, pure cotton in this structure still allows substantial airflow. In contrast, CSJ displayed the lowest porosity value at 97.63%, Implying that cotton on its own is less breathable compared to bamboo and banana blends, even in a single jersey knit.

The BNCSJ sample reached a porosity of 98.01%, reflecting the beneficial contribution of banana fibre to breathability. Meanwhile, the rib knitted blends BMCRB and BNCRB exhibited slightly lower porosities of 97.68% and 97.73%, respectively, which can be attributed to the tighter and more structured rib knit formation.

In conclusion, the results clearly indicate that the both fibre type and knitting technique significantly affect the porosity of socks. Blended yarns incorporating bamboo and banana fibres, particularly in a single jersey knit, enhance air permeability and are therefore more suitable for applications requiring high breathability and wearer comfort.

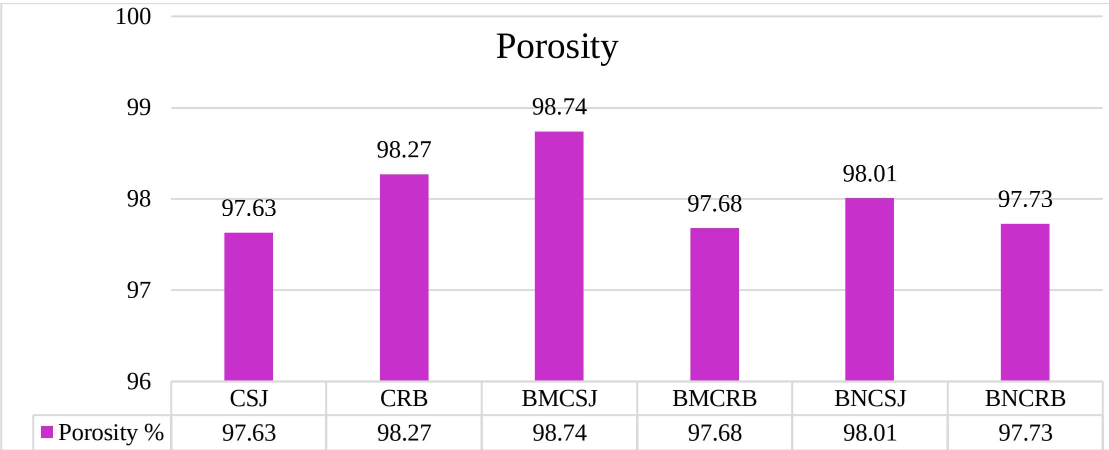


Figure 3: Porosity of Socks produced

Moisture Management of Socks

Sample	**Wetting Time Top (Sec)**	**Top Absorption Rate (%)**	**Top Maximum Wetted Radius**	**Top Spreading Speed**
CSJ	9.094	109.6331	5.0	0.3463
CRB	17.25	451.0874	5.0	0.2867
BMCSJ	0.844	76.9782	10.0	0.4716
BMCRB	13.969	184.9424	5.0	0.3532
BNCSJ	11.812	459.4452	10.0	0.9089
BNCRB	12.844	322.9408	5.0	0.3837

Table 5: Absorbency of Socks Produced (Top)

The wetting and absorption performance varied notably across the tested samples. BMCSJ demonstrated the shortest wetting time (0.844 seconds) and the highest spreading speed (0.4716), indicating efficient and rapid fluid uptake and distribution. Conversely, CRB exhibited the longest wetting time (17.25 seconds) and a relatively low spreading speed (0.2867), despite its high absorption rate of 451.09%. BNCSJ recorded the highest absorption rate (459.45%) and the fastest spreading speed (0.9089) among samples with a maximum wetted radius of 10 mm. Although both BNCSJ and BMCSJ shared the same wetted radius, BNCSJ absorbed more fluid but required a longer time to wet the surface. Samples with a 5 mm wetted radius, including CSJ, CRB and BMCRB, generally exhibited lower spreading speeds and absorption efficiencies. These results suggest that a larger wetted radius is generally associated with enhanced spreading performance and in some cases, improved wetting efficiency.

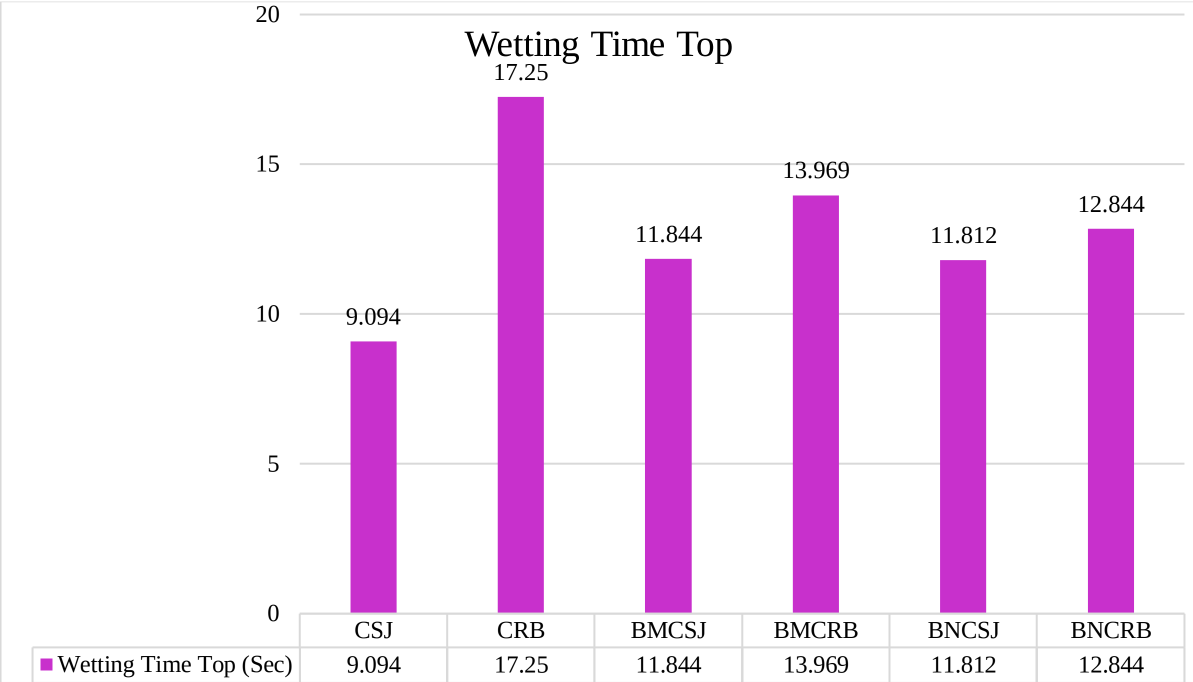


Figure 4: Top Wetting time of Socks produced

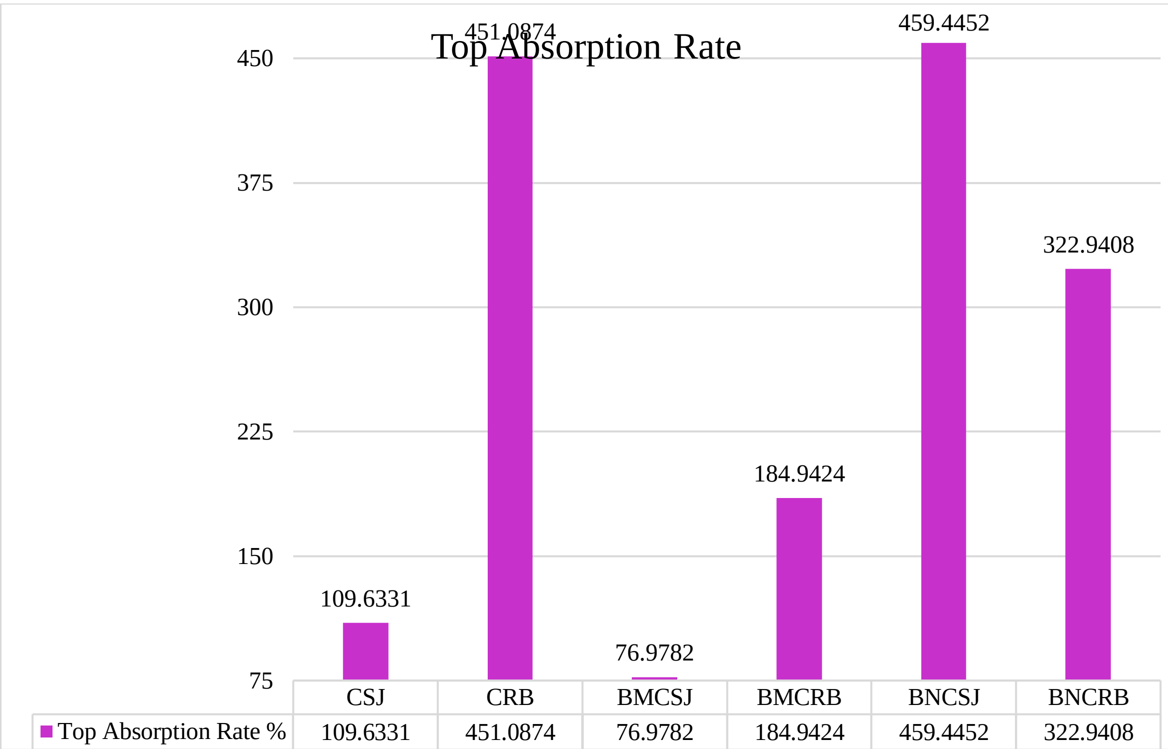


Figure 5: Top Absorption Rate of Socks produced

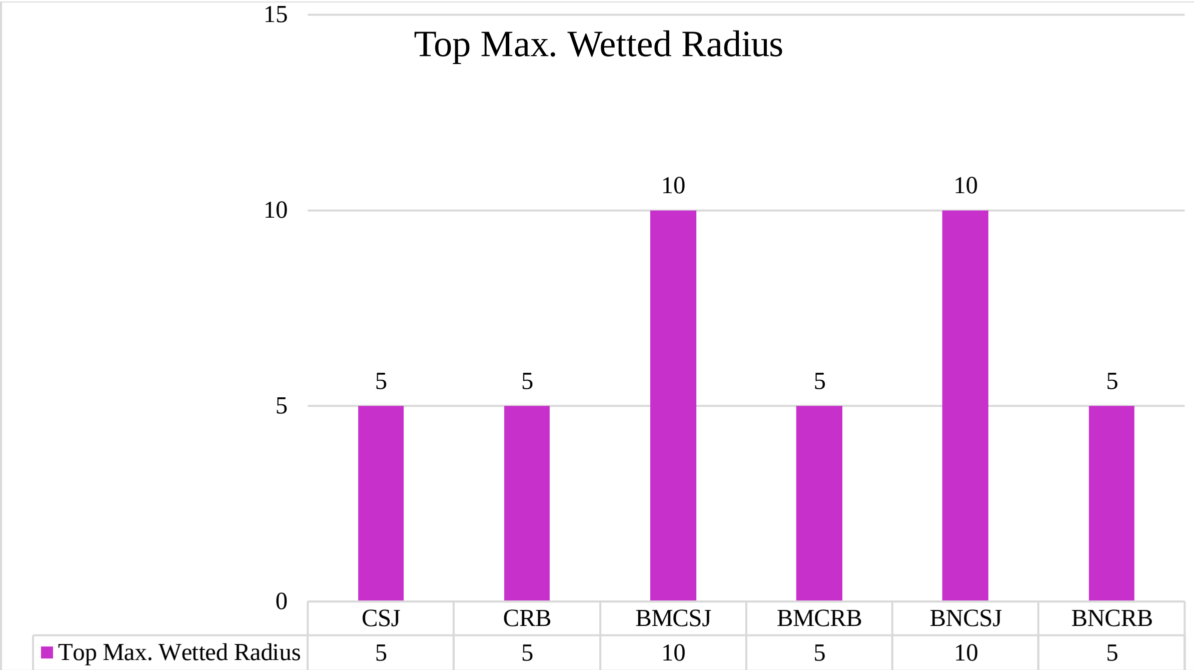


Figure 6: Top Max Wetted Radius of Socks produced

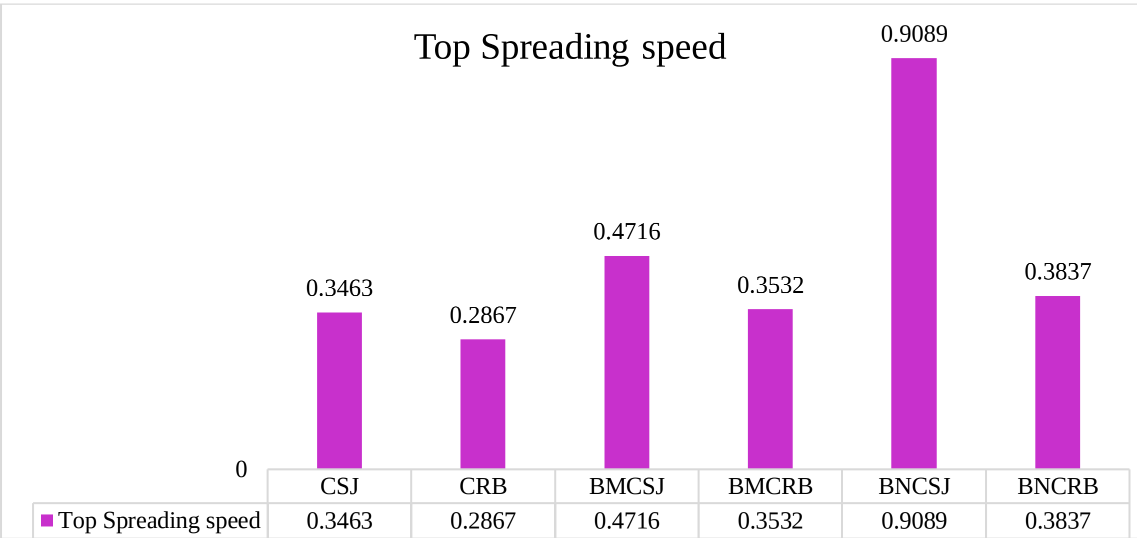


Figure 7: Top Spreading speed of Socks produced

Sample	**Wetting Time Bottom (Sec)**	**Bottom Absorption Rate (%)**	**Bottom Maximum Wetted Radius**	**Bottom Spreading Speed**
CSJ	120.0	65.0097	5.0	0.4267
CRB	120.0	67.897	5.0	0.328
BMCSJ	120.469	13.9005	15.0	2.0118
BMCRB	120.0	18.634	10.0	2.950
BNCSJ	120.0	15.2357	15.0	3.5321
BNCRB	130.312	26.085	5.0	0.3704

Table 6: Absorbency of Socks Produced (Bottom)

The bottom layer wetting and absorption characteristics revealed marked variations across the tested samples. Wetting times were uniformly prolonged, with most samples reaching or exceeding 120 seconds; notably, BNCRB exhibited the longest wetting time at 130.312 seconds. Among the samples with a 15 maximum wetted radius, BMCSJ demonstrated the highest spreading speed (2.0118), while BNCSJ surpassed all others with the fastest spreading speed overall (3.5321), despite exhibiting a relatively modest absorption rate of 15.24%. In contrast, CSJ and CRB, both characterized by a 5 mm wetted radius, displayed significantly slower spreading speed (0.4267 and 0.328, respectively) but achieved the highest absorption rates (65.90%). These findings suggest that while greater absorption may be associated with smaller wetted areas, a larger wetted radius tends to facilitate more rapid and efficient fluid distribution across the bottom surface.

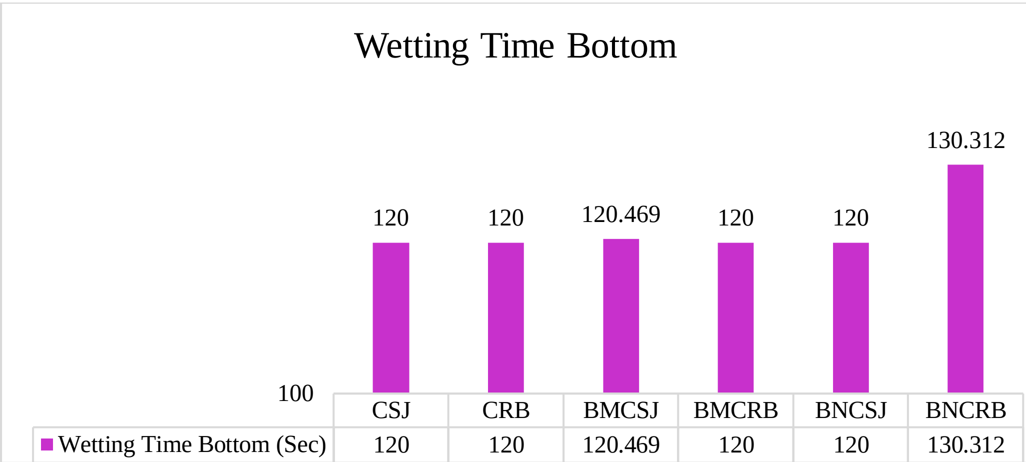


Figure 8: Bottom Wetting time of Socks produced

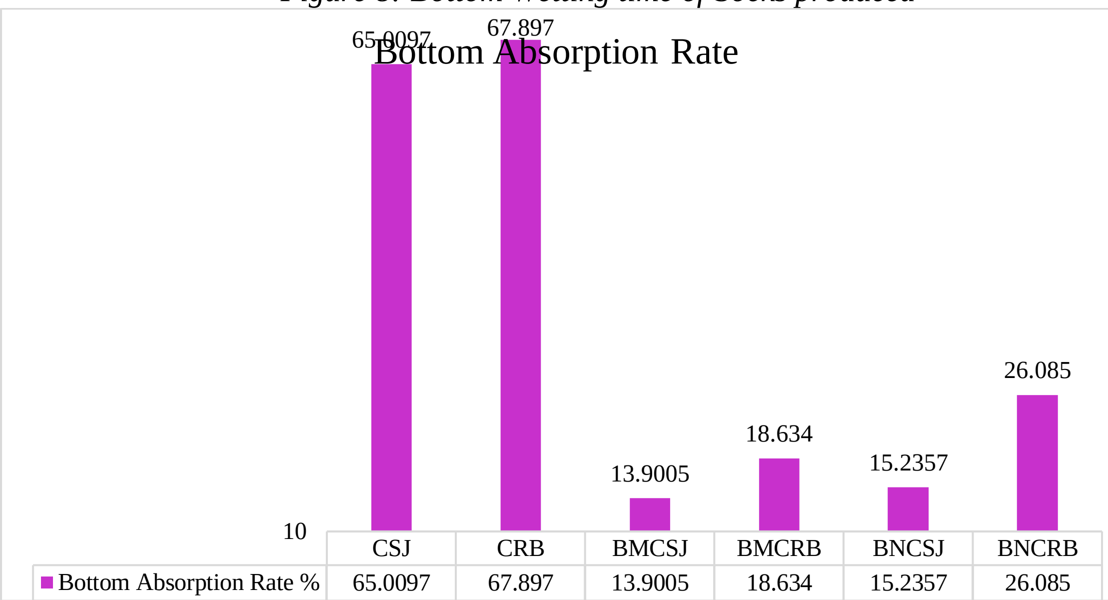


Figure 9: Bottom Absorption Rate of Socks produced

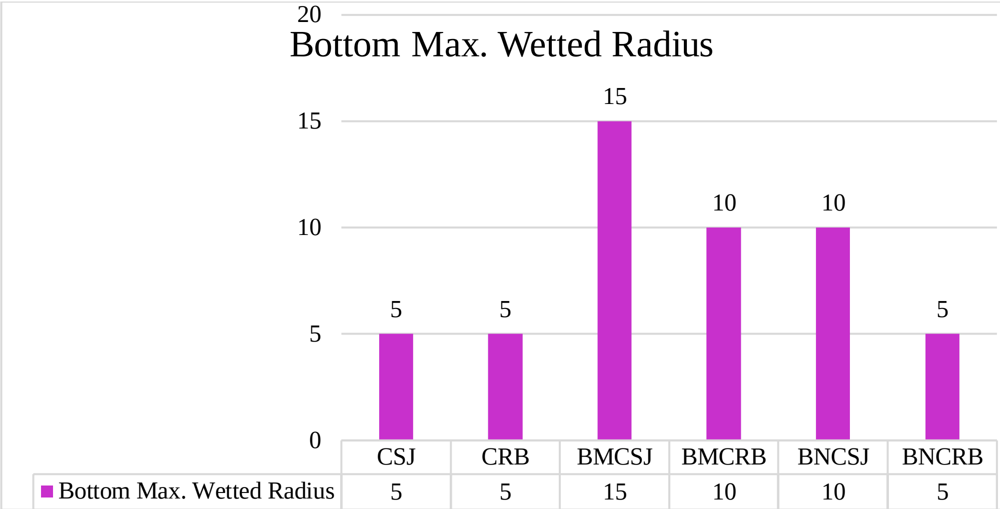


Figure 10: Bottom Max Wetted Radius of Socks produced

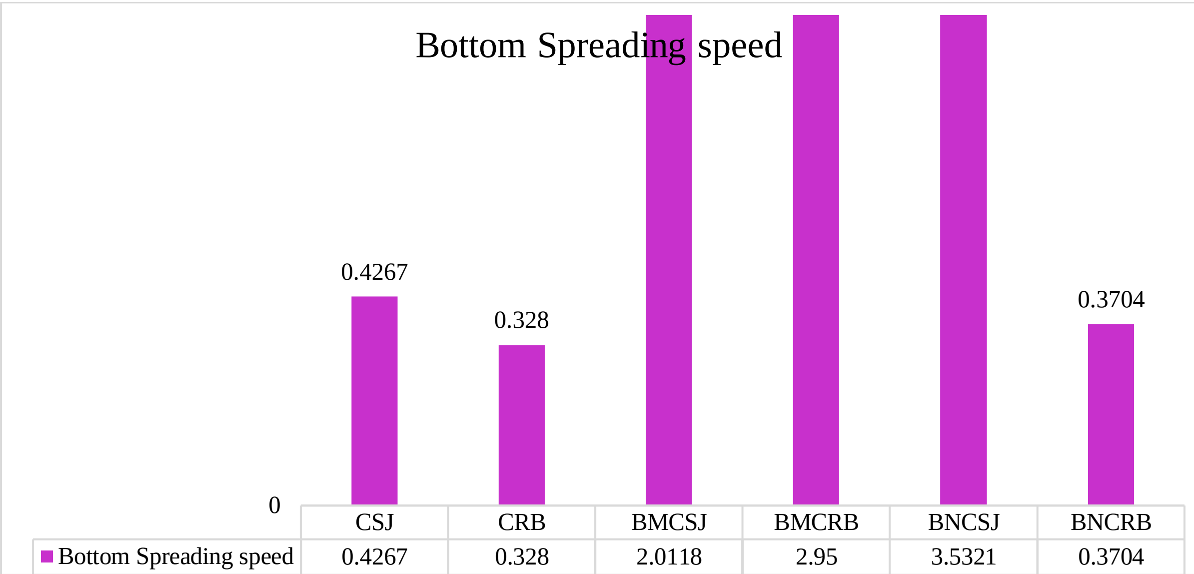


Figure 11: Bottom Spreading speed of Socks produced

Sample	**Accumulative One Way Transport Capability**	**OMMC**
CSJ	-1091.3123	0.6528
CRB	-1075.1074	0.4387
BMCSJ	-679.19	0.0952
BMCRB	-1106.2673	0.0863
BNCSJ	-886.1756	0.2256
BNCRB	-262.8214	0.0447

Table 7: One way transport capability and OMMC of Socks Produced

The analysis of accumulative one way transport capability and overall moisture management capacity (OMMC) reveals notable variation in te moisture handling efficiency of the samples.

CSJ recorded the highest OMMC value (0.6528), indicating strong overall moisture management performance, despite a highly negative on way transport capability (-1091.31). CRB followed with a moderate OMMC of 0.4387 and a similarly negative transport value (-1075.11). Interestingly, BNCRB exhibited the least negative transport capability (-262.82), yet its OMMC was the lowest among all samples (0.0447), suggesting limited effectiveness in managing moisture. Both BMCSJ and BMCRB showed poor moisture management, with low OMMC values (0.0952 and 0.863, respectively) and notably negative transport capabilities. These results imply that a less negative transport capability does not directly equate to better overall moisture management, underscoring the complex interplay between directional transport and total moisture handling performance.

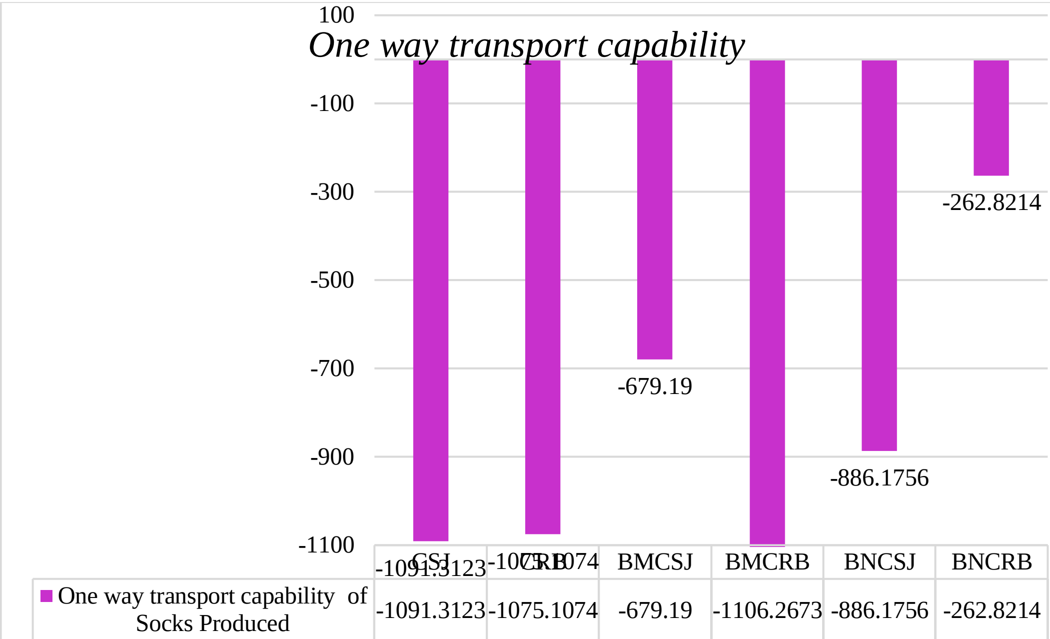


Figure 12: One way transport capability and of Socks Produced

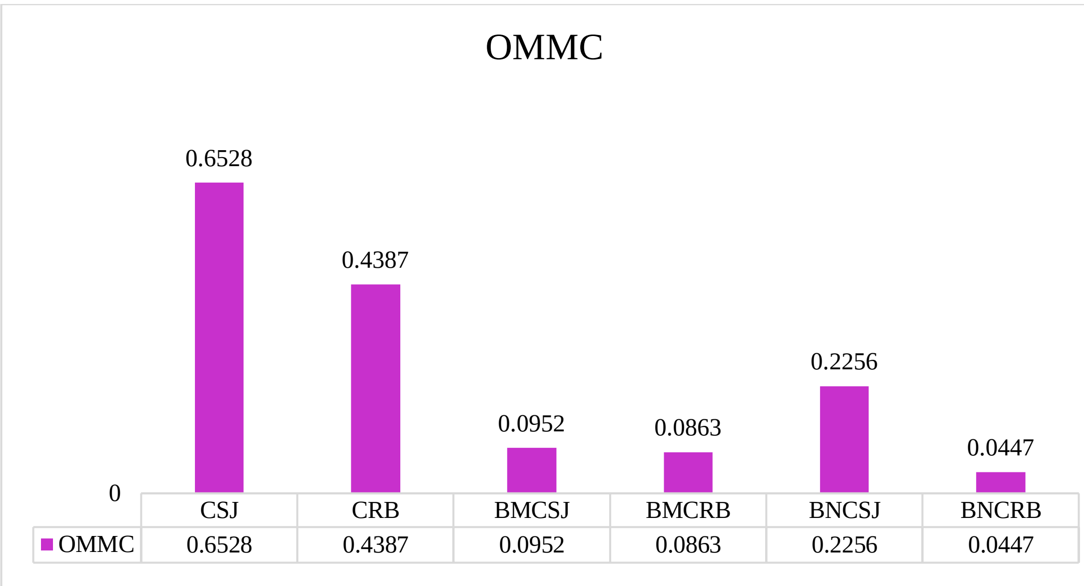


Figure 13: OMMC of Socks produced

Conclusion

The comprehensive evaluation of the sock's physical, structural and moisture management characteristics highlights the critical role that both fibre composition and knitting structure play in determining overall performance. Among all the samples, BMCSJ (40% bamboo / 60% cotton single jersey) demonstrated exceptional breathability, recording the highest air permeability (51.50 cc/sec/cm^2) and porosity (98.74%). These attributes are largely attributes to the porous nature of bamboo fibres combined with the more open construction of the single jersey knit, making this sample particularly well suited for warm climates or high activity use where ventilation and moisture evaporation are essential.

In terms of moisture management, BNCSJ (40% banana / 60% cotton single jersey) outperformed other samples in top layer absorption rate and spreading speed, suggesting effective wicking and fluid dispersion on the surface. However, the rib variant of the same composition, BNCRB, while showing the lowest negative one way transport capability (-262.82), also recorded the poorest OMMC (0.0447), indicating inefficient overall moisture transfer from the inner to outer surface. This suggests that a less negative transport value does not necessarily correspond to improved moisture management performance, pointing to the complexity of interactions between fabric layers and directional moisture flow.

CSJ (100% cotton single jersey) emerged as a strong performer in terms of balanced moisture management, achieving the highest OMMC value (0.6528) despite a significantly negative transport capability (-1091.31). This implies that although directional moisture transport was limited, the fabric still managed moisture effectively through absorption and spreading. On the contrary, samples like BMCRB and BNCRB, despite being thicker and structurally more robust, offered limited moisture handling capabilities due to their denser rib knit, which restricts both air and moisture movement.

Overall, the study confirms that the single jersey knits generally provide superior breathability and dynamic moisture handling compared to rib structure. Additionally, blending natural fibres like bamboo and banana with cotton enhances specific functional properties such as porosity and surface moisture dispersion. However, these advantages do not always translate into improved directional moisture transport, as reflected in OMMC values. Therefore, for optimal sock performance whether for sportswear, casual use or thermal applications it is essential to strategically align fibre type, yarn composition and knit structure to meet the desired end use requirements.

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