TEKSTİL VE KONFEKSİYON

VOL: 35, NO. 1
DOI: 10.32710/tekstilvekonfeksiyon.1576815

Terry and Single Jersey Fabrics Knitted with Porous Yarns for Enhanced Sock Performance

Tuba Bedez Ute[1] 0000-0003-0574-2874
Pinar Celik[1] 0000-0003-3558-4213
Matejka Bizjak[2] 0000-0003-0361-9784

[1]Ege University, Faculty of Engineering, Department of Textile Engineering, Izmir, Turkiye
[2]University of Ljubljana, NTF Department of Textiles, Graphics Arts and Design, Ljubljana, Slovenia

Corresponding Author: Tuba Bedez Ute, tuba.bedez@ege.edu.tr

ABSTRACT

Innovations in fiber, yarn, and fabric structures are being implemented to enhance product properties. One of the methods preferred for this purpose is modifying the internal structure of the yarn by reducing the density of the yarns. This study investigates the effects of natural-based raw material and internal yarn structure on the properties of yarns and fabrics. Core-spun yarns were produced in a ring-spinning system to obtain loose structures for the design of sock fabrics. Environmentally friendly polymer-based soluble filament yarns were used instead of polyvinyl alcohol (PVA) as the core, in two different thicknesses, in order to obtain different internal yarn structure. Cotton, blends of bamboo/cotton and cotton/viscose fibers were used as the sheath material. Single jersey and terry fabrics, which are among the most preferred fabric structures in sock production, were produced using these yarns. After finishing processes, fabrics made from loosely structured yarns were obtained. The yarns' and fabrics' mechanical and permeability properties were measured. The knitting structure, raw material composition, and yarn structure significantly influence the properties of sock fabrics. Utilizing loose yarn structures enhances comfort characteristics without adversely affecting critical mechanical properties, such as bursting strength. Cotton fabrics have demonstrated better moisture management, air permeability, and bursting strength compared to regenerated cellulosic fiber-containing fabrics, making them preferable for sock production. Incorporating loose yarns in terry structures, favored for their softness and moisture absorption in socks, has positively impacted the desired fabric performance.

ARTICLE HISTORY
Received: 31.10.2024
Accepted: 05.03.2025

KEYWORDS
Core spun, water absorption, moisture management, air permeability, socks, yarn structure, porous structure

1. INTRODUCTION

In recent years, there have been significant advances in fiber, yarn, and fabric technology. A significant part of these developments aims to increase the comfort of clothing. Regarding comfort, issues such as liquid absorption and moisture management of fabrics have attracted the attention of many researchers. Heat and moisture transfer processes in porous textile structures have been extensively studied, with research focusing on various influencing factors. These include the moisture absorbency properties of fibers, as well as fabric thickness and porosity [1, 2]. The role of the twist of multifilament polyester yarn [3] and nylon/cotton core-spun yarns' properties [4] in capillary wicking behavior has also been explored. Investigations have addressed the impact of various cotton fiber types on water vapor transfer in knitted fabrics [5] and the moisture transfer properties of soybean fiber-cotton blend fabrics [6]. Studies on the assessment of the wicking performance of fabrics [7], moisture management characteristics in knitted fabrics [8-11], and the thermal and moisture transfer behavior of hollow yarns and micro-porous yarn structures in knitted fabrics [12, 13] contribute to the literature.

The most important properties required of socks are abrasion resistance, elasticity, dimensional stability, and thermal comfort [14]. The quality of socks is influenced by many factors, such as raw materials, yarn properties, knitting conditions, and finishing process [15]. Thermal properties

To cite this article: Bedez Ute T, Celik P, Bizjak M. 2025. Terry and Single Jersey Fabrics Knitted with Porous Yarns for Enhanced Sock Performance. *Tekstil ve Konfeksiyon*, 35(1), 41-53.

and sweat dissipation during wear are essential for the health and comfort of the user. The socks on the market are made from different raw materials such as cotton, viscose, bamboo, modal, polyester, acrylic, wool, and their blends. Some researchers studied the comfort properties of plain knitted, plaited, and terry-knit socks made from different yarn materials and yarn types [14-24]. Khalil et al. investigated the optimization of sports compression socks' characteristics for athletic applications [22].

Pile fabrics, such as terry fabrics, have a higher water absorption capacity than other textile fabrics [23-25]. The thickness of the fabric is the most critical parameter affecting comfort parameters such as air permeability and water vapor permeability [19, 26]. As fabric thickness increases, the fabric's volume increases, affecting its porosity, an essential parameter for permeability. After wet finishing, the weight and thickness of the fabric increase, and the porosity decreases. Yarns and fabrics become more voluminous due to shrinkage and the fibers' crimped structure, so the fabric's thermal conductivity decreases due to the higher insulating property of the air gaps in the voluminous spaces.

Similarly, the porosity in the yarn structure is as important as the porosity in the fabric structure. For this purpose, the hollow yarn structure is widely used in industry today, especially in producing towels as pile yarn. The preferred method for producing hollow yarns is core yarn spinning. Core yarns are produced by feeding a filament yarn onto the delivery roller of a modified ring spinning frame [27]. Different yarn properties can be obtained by changing the production parameters such as material type, thickness, core-sheath ratio, yarn count, and twist properties [28, 29]. In producing hollow yarns, a soluble filament yarn is used in the core part to improve the functional properties of the fabric [30, 31]. Since hollow yarns are spun from staple sheath fibers, even if the core filament in the center is removed, a continuous hollow in the longitudinal direction, which occurs in filament hollow yarns, cannot be obtained. Rather, a porous yarn structure is obtained [8].

The effects of twist coefficient, core material thickness, and core material tension on capillarity were studied, and higher capillarity was obtained with decreasing twist and yarn count (Ne) [8]. Pourahmad and Johari investigated the effects of some spinning parameters, such as filament pretension, on the properties of the ring, Siro, and solo yarns with acrylic sheath and nylon core, which they had produced using different spinning methods [32]. Ishtiaque et al. studied the effects of PVA ratio, yarn ply twist, spindle rotation speed, and their interactions on the properties of microporous yarns [33].

Various production methods can produce hollow yarns. Merati and Okamura studied the production of hollow yarns using the friction spinning method [34-36]. Ma and Xia investigated the properties of cotton-covered polyvinyl alcohol (PVA) core yarns with different twist directions produced by the core yarn method [37]. PVA multifilament was used to produce core-spun, blended double pre-hollow yarns and knitted single jersey fabrics. They concluded that with a higher yarn packing coefficient, wicking in the hollow yarn fabrics increased while water absorption decreased [38].

Many researchers investigated the effects of the hollowness ratio, the type of sheath material, and the yarn spinning method on plain knitted fabrics' mechanical and comfort properties [9, 39-42]. The thermal comfort properties of knitted fabrics made from different hollow yarns were investigated [9]. Woven fabrics from hollow cotton yarns spun with Kuralon K- II were produced and their thermal comfort properties were analyzed [43]. Senthilkumar focused on the structural properties of knitted fabrics made from hollow cotton yarns and found them to have a lighter and looser structure with less spirality [44]. Gungor Turkmen et al. studied the effects of hollow yarn type on the structure of woven fabrics [45, 46].

The packing density of the yarn influences the yarn structure. Hollow yarns have lower yarn density and are more voluminous due to the removal of the core parts after washing, so the use of this type of yarn in fabric alters the comfort properties, especially air permeability, water vapor permeability, and wicking properties [38, 41, 47]. Hollow yarns are particularly preferred in the production of terry fabrics. As mentioned, many studies on plain knitted fabrics with hollow yarns are in the literature. However, few studies were found on the mechanical and comfort properties of terry fabrics with hollow yarns. When reviewing the previous studies, it was found that the effects of different yarn types and fiber types on the comfort properties of plain knitted fabrics were mainly investigated in studies on the comfort properties of socks [14-21]. Only Morgil investigated the comfort properties of terry knitted socks made from different raw materials [22]. The effects of properties such as weft yarn count, weft density [48], pile height, and fiber type are primarily investigated in the studies on terry woven fabrics.

The study aimed to enhance the comfort properties of knitted fabrics used in socks by utilizing a yarn structure characterized by loose and porosity. This loose structure increases breathability and reduces weight, increasing overall comfort. The innovative and environmentally friendly fiber used in the production of core-spun yarns and using loose and porous yarns in hosiery production are two main original aspects of this study. The ring spinning method was used to produce core-spun yarns with different sheath materials and core ratios. Two different fabric structures (terry and single jersey) were selected for sock fabrics. The effects of yarn properties on the performance of single jersey fabrics have been investigated in a previous study. However, in this study, a comprehensive and comparative analysis was performed with terry cloth besides single jersey fabric [18]. In addition to the main fabric properties, liquid absorption and moisture management properties were also investigated.

Plain and terry knit fabric structures are preferred in the sock manufacturing industry; however, a significant gap in the literature regarding the influence of different fiber types and yarn densities on knitted terry socks' comfort and fabric characteristics. Hence, the study focuses on developing terry and single jersey socks with variable porous and loose yarn structures and fiber compositions to obtain comfort and performance characteristics. Unlike previous studies [14-22], the effect of porous and loose yarn structure on the properties of terry-knitted socks was investigated. Additionally, single-jersey knit fabric structures were included to evaluate the impact of yarn structure on permeability properties across different fabric structures, enabling a comparative analysis of their performance relative to terry-knit fabrics.

2. MATERIALS AND METHODS

The influence of the raw material and the yarn compactness on the single jersey and terry fabric's mechanical and comfort properties were investigated. 100% cotton, 50/50% viscose/cotton, and 70/30% regenerated bamboo/cotton rovings were used as the sheath, and soluble fully drafted filament (FDY) yarn was used as the core material (Table 1). Polymer-based soluble filament, used in the core, was composed of modified polyethylene terephthalate-co-polyethylene glycol (PET/PEG) copolymer. Since the properties of the fabrics are affected by different porous structures of the yarn caused by different ratios in the core material, the fineness of 56 dtex filament and 168 dtex filament was used as the core material. It was not possible to obtain the core filament in different thicknesses thus, it was preferred to fold it three times in order to provide varying amounts of void within the yarn.

The cotton fibers used in the study have a fineness of 3.8 mic. and a mean length of 33.38 mm, while regenerated bamboo and viscose fibers have a length of 38 mm and a fineness of 1.3 dtex. The blended sheath materials (50/50 viscose/cotton and 70/30 regenerated bamboo/cotton) were obtained by blending in the blowroom line and used as roving for the yarn production. The materials used in this study were selected from the fibers most preferred in sock production. These fibers were supplied in roving form from the industry, and it was not possible to obtain them in the same blend ratios. The yarns, produced using different core thicknesses and sheath fibers, were spun on the Pinter Merlin ring spinning machine at 7,000 rpm using the ring core spinning method. The final yarn count (59 tex) was the same after the core material was removed. The yarn linear densities of raw core-spun yarns are given in Table 1. The draft ratio was set according to the sheath fiber amount. Thus, the amount of sheath fiber was the same for all samples, resulting in the same final yarn count, to enable a better comparison.

Consequently, all yarns have the same yarn count after washing, but the fiber orientation and distribution in the yarn differ depending on the fineness of the core material used. According to Fig. 1, it can be seen that the core material has been removed after washing. After removing the core part by washing, the structure of the yarn using a 3x56 dtex filament core will be looser than that of the yarn using a 56 dtex filament core. Yarns without a core will naturally exhibit a more compact structure after washing, as no voids form within them. However, in terminology, compact yarns are typically described as yarns with low hairiness. In this study, the term "compact yarn" refers not to the yarn's hairiness but to the closer arrangement of fibers within the structure. In the following sections, standard ring-spun yarns produced without using core material are named reference yarns.

Single jersey fabrics in tubular form were produced on a labknitter (Mesdan Labknitter, 3.3/4 inch 140 needles). Terry socks are produced on a single-cylinder sock-knitting machine (Lonati, 3.3/4 inch 156 needles). Machine adjustments were kept the same during all productions.

Single jersey and terry fabrics were knitted under the same conditions to study the effects of the produced yarns on the different fabric structures. The fabrics were hydrophilized, and the filament yarn was removed simultaneously to obtain a porous and loose structure. The knitted fabrics were washed with a 5 g/l NaOH solution at 100 °C for 1 hour. Then, the filament in the core was removed by hot, warm, and cold rinsing, and instead of the hollow structure, a looser structure was obtained. The fabric samples were dried in daylight.

All the yarn and fabric samples were conditioned for 24 hours under standard laboratory conditions according to TS EN ISO 139. Performed yarn and fabric tests, test instruments, related standards, and the number of specimens and repetitions are given in Table 2.

The values for yarn tenacity (cN/tex) and breaking elongation (%) of yarns after removal of the core parts were tested. The distance between jaws was set to 250 mm, the test speed was 250 mm/ min.

Test samples were collected from 18 different types of knitted fabrics (5 specimens for each type), and the fabric weight, thickness (20 cm^2, 200 g weight), air permeability (100 pascals, 20 cm^2), and bursting strength values were measured [49].

Table 1. Sample codes and definition (C: Cotton, CV: Cotton/viscose, CB: Bamboo/cotton)

Codes	Sheath	Core	Sheath / Core ratio	Yarn linear density (tex)
C0	100% Cotton	-	100/1	59
C1		56 dtex FDY PET	91 / 9	64.7
C2		3x56 dtex FDY PET	78 / 22	74.8
CV0	50/50 Cotton/ Viscose	-	100/1	59
CV1		56 dtex FDY PET	91 / 9	64.7
CV2		3x56 dtex FDY PET	78 / 22	74.8
CB0	70/30 Bamboo/Cotton	-	100/1	59
CB1		56 dtex FDY PET	91 / 9	64.7
CB2		3x56 dtex FDY PET	78 / 22	74.8

Table 2. Yarn and fabric tests.

	Test	Test Instrument	Test Standard	Test repetitions
Yarn	Breaking tenacity	Lloyd Instrument	ISO 2062	5x30
	Elongation at break	Lloyd Instrument	ISO 2062	5x30
Fabric	Weight		EN 12127	5x5
	Thickness	SDL Atlas M034A	ISO 5084	5x10
	Air permeability	Textest Instruments/FX3300	ISO 9237	5x10
	Bursting strength	Pneumatic	ISO 13938-1	5x10
	Hydrophilicity	Single jersey: Capillary rise Moisture management (MMT test)	AATCC 197 AATCC 195	3
		Terry fabrics: Penetration test	TS 629	3

The hydrophilicity properties of single jersey and terry fabrics were evaluated using different test methods due to different fabric construction. While the capillary rise of liquid (height) test was used for single jersey fabrics, measurements were made according to the penetration test for terry fabrics. Three samples (2 x 2 cm) were cut out from the terry fabrics. The test is performed by dropping the samples from a height of 5 cm into 10 cm of pure water in a beaker with a suitable diameter. This method is based on the immersion times (in seconds) to determine the water absorption properties. The stopwatch was started when the fabric surface touched the water. It was stopped when the fabric was completely immersed in the water. The value read is the immersion time for the sample. The average value of the immersion times for three samples of the same fabric is the sinking time. The shorter the sinking (soaking) time, the higher the hydrophilicity of the fabric.

For the capillary rise of liquid (height) test used for single jersey fabrics, samples cut into 25x3 cm were immersed in a beaker of pure water (a yellow dye had been added). The capillary rise of the liquid (height) of the water was measured by a ruler at different periods (1 minute, 5 minutes, 10 minutes, 20 minutes, 30 minutes, and 60 minutes) [50]. On the other hand, the capillary rise test of the single jersey fabrics shows that all fabrics have the same capillary rise rapidly. Therefore, Moisture Management Tester (MMT-SDL Atlas) was used to test the moisture management properties of single jersey fabrics. This device dynamically measures the moisture management capacities of textiles. Moisture transmission with the device is determined by measuring the electrical resistance of the fabric. Two factors influence this value: the components of water applied to the fabric and the amount of water contained in the fabric. Since the first factor was kept constant in the tests, the logic of measuring the moisture transmission management of the device is to change the electrical resistance of the water ratio in the fabric and determine this change [3, 7, 51]. MMT tests yield values such as wetting time, absorption rate, spreading rate, and OMMC. OMMC, Overall Moisture Management Capacity, is an index value used to understand the moisture transmission management of the fabric in general. A high value indicates a high moisture management capacity [3, 7].

The fabrics' porosity values were calculated according to Equation 1 [52].

$$\varepsilon\,(\%) = \left(1 - \frac{\rho_{fabric}}{\rho_{fibre}}\right)*100 \qquad (1)$$

$$\rho_{fabric} = \frac{M_{fabric}}{t} \qquad (2)$$

In Equation 1 and Equation 2, ε is the total porosity (%); ρ_{fabric} is fabric density (g/cm^3); ρ_{fiber}, is the fiber density (g/cm^3); M_{fabric} is the fabric weight (g/cm^2) and t is the fabric thickness (cm). The fiber densities for cotton, viscose, and bamboo were taken as 1.54, 1.52, and 1.32 g/cm^3 respectively. The average fiber density has been calculated based on their proportions in the mixture [53, 54].

The impact of yarn type on fabric properties was examined through one-way analyses of variance.

Levene's test for homogeneity of variance was utilized to evaluate the essential ANOVA assumption that each independent variable group had its variance. This test was crucial in determining whether the variances of the groups were heterogeneous (leading to the Tamhane T2 post-hoc test) or homogeneous (resulting in the application of the Student-Newman-Keuls (SNK) multiple range test), guiding the selection of the appropriate post-hoc test. Further post-hoc tests were implemented to understand better the effects of different yarn structures (loose-compact) on fabric structures and raw materials. Consequently, the results will be analyzed separately in the following section, as comparing different knitted fabric structures is deemed inappropriate [55].

3. RESULTS AND DISCUSSION

Yarn test results

The core material was removed to examine the yarn structure, and SEM images were taken in yarn form. After removing the core material, the yarn structure was no longer hollow. However, it became looser after washing, the gaps between the fibers increased, and the sheath fibers collapsed inwards (Fig. 1). In other words, the area emptied by the core material was not protected. However, it is partially covered by the migration of the surroundings.

Since the core filament was removed after fabric production, the yarn diameter did not change significantly due to fabric shrinkage despite the viscose and bamboo fibers contracting during wet processing. However, the porosity within the internal structure of the yarn increased. Results for 100% cotton yarns [44], and viscose-based fabrics [53] were consistent with the literature. The shrinkage effect in cotton/viscose blended fabrics is not very noticeable due to the 50% cotton content. However, in 70/30 bamboo/cotton blended fabrics, the higher bamboo content makes the impact of shrinkage more pronounced, regarding yarn structure.

Depending on the filament structure of two different thicknesses (56 dtex and 3x56 dtex) used in the core part of the yarn, the two yarn structures have different yarn densities and inter-fiber air gaps. The images of SEM (Fig. 1-b, 1-d, and 1-f) do not show a distinct hollow structure after washing, where the core yarn is no longer present, as the gap is partially closed by the surrounding fibers so that the yarn density has decreased as the fibers move to the center of the yarn. The yarn structures eventually became porous and loose compared to the ring yarn.

Hollow yarns produced using the core-spun yarn production technique should be evaluated separately from hollow fibers since the circular void within the material is preserved in hollow fibers, whereas, in spun yarns, the circular void cannot be maintained due to internal stresses on the fibers caused by twisting and drawing processes. However, this results in the yarn having a looser structure.

Yarn diameter measurements were taken for raw and washed yarns by using ImageJ software; the results are presented in Table 3. The data showed no statistically significant difference in the diameters of the raw yarns. After removing the core material, there was still no significant difference in the diameter measurements, except for the CB1 yarns, which had a larger diameter than the others, with a statistically significant difference (Table 3). In this study, when a 56 dtex filament was used in the core of cotton/viscose and bamboo/cotton yarns, the yarn diameter increased depending on the shrinkage ratio of the fibers. However, when the filament thickness increased to 168 dtex, the amount of voids increased significantly, making this effect more dominant. As a result, the fibers rearranged, redistribution was occurred, thus reducing the impact of fiber shrinkage.

The yarn tenacity and breaking elongation (%) were tested after removing the core component; the results are shown in Fig. 2.

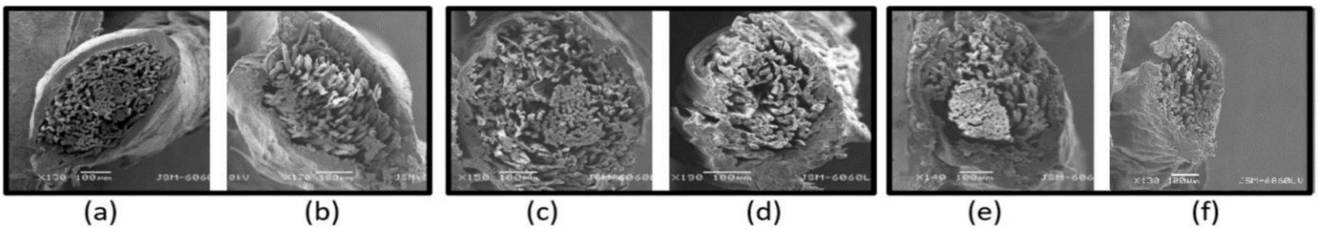


Fig. 1. SEM images of C2 yarns (a) before (b) after washing, CV2 yarns (c) before (d) after washing, and CB2 yarns (e) before (f) after washing.

Table 3. Yarn diameters (μm) calculated from SEM Images.

	Cotton			Cotton/ Viscose			Bamboo/Cotton		
	C0	**C1**	**C2**	**CV0**	**CV1**	**CV2**	**CB0**	**CB1**	**CB2**
Before	395.36	394.34	455.02	358.89	397.71	458.71	380.62	415.63	407.71
After	377.67	373.90	419.65	339.27	408.94	368.45	368.27	457.15	342.33
Sig.*	**p value: 0.464**			**p value: 0.082**			**p value: 0.000**		

*Significant for $\alpha = 0.05$.

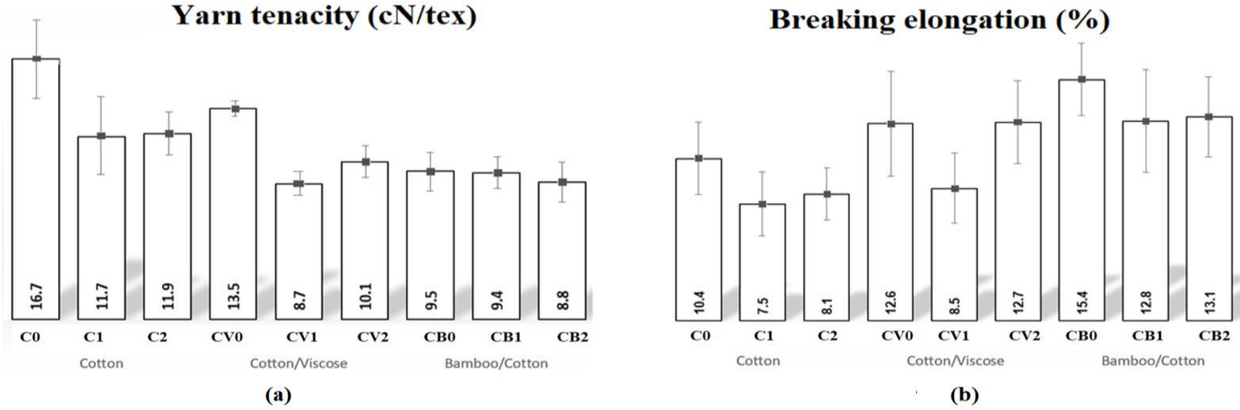


Fig. 2. Breaking tenacity (a) and breaking elongation (b) of the yarns.

According to the test results of tenacity and elongation at the break, the values decreased with looser yarn structures (Fig. 2), compared to reference yarns. Cotton yarns were found to have the highest values for tenacity and the lowest values for breaking elongation (%). In the error bar analysis (with a 95% confidence interval), the breaking strength values of the reference yarns produced from 100% cotton and cotton/viscose fibers were found to be statistically significantly higher compared to the core-spun yarns. However, no significant difference was observed between the values of the core-spun yarns. When the elongation at break values of cotton and cotton/viscose yarns were examined, no significant differences were observed between them. These results are parallel with a previous study [39].

On the other hand, in bamboo/cotton yarns, the effect of yarn structure on tensile strength and elongation at break was not found to be statistically significant.

Fabric test results

Microscopic views of some knitted structures and test results for fabric weight, thickness, air permeability, bursting strength, and fabric porosity of terry and single jersey fabrics are given in Fig. 3, Fig. 4, and Fig 5 respectively.

One-way ANOVA was applied to investigate the effects of different yarn structures (loose-compact) on the weight, thickness, strength, air permeability, and water absorbency of cotton, cotton/viscose, bamboo/cotton terry, and single jersey fabrics. The results of the analysis of variance are shown in Table 4.

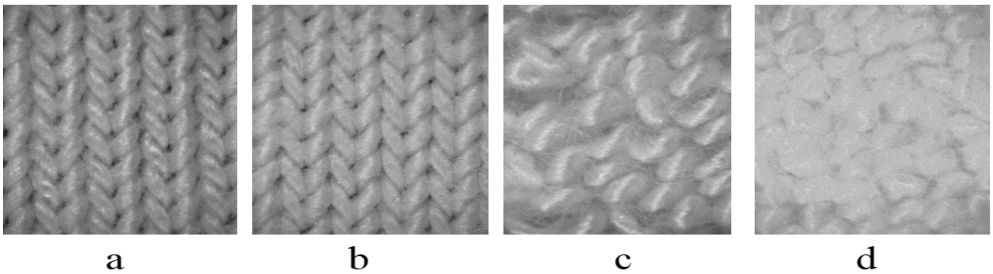


Fig. 3. The microscopic views of single jersey (a) before (b) after washing and terry fabrics (c) before (d) after washing. (Motic microscope, magnification x400)

Table 4. The effect of different yarn structures on fabric properties (One-way ANOVA)

	Terry fabric			Single-jersey fabric		
	Cotton	Cotton/ Viscose	Bamboo/ Cotton-	Cotton	Cotton/ Viscose	Bamboo/ Cotton-
	Sig.*	Sig.*	Sig.*	Sig.*	Sig.*	Sig.*
Weight g/m^2	**0.000***	**0.001***	**0.000***	**0.000***	0.082	**0.021***
Air permeability	**0.002***	0.023	**0.000***	**0.000***	**0.000***	**0.000***
Bursting strength	0.291	0.349	0.238	**0.000***	0.928	**0.005***
Thickness	**0.000***	**0.000***	**0.005***	**0.013***	0.591	**0.000***
Water absorption	**0.018***	0.678	**0.022***			

*Significant for $\alpha = 0.05$.

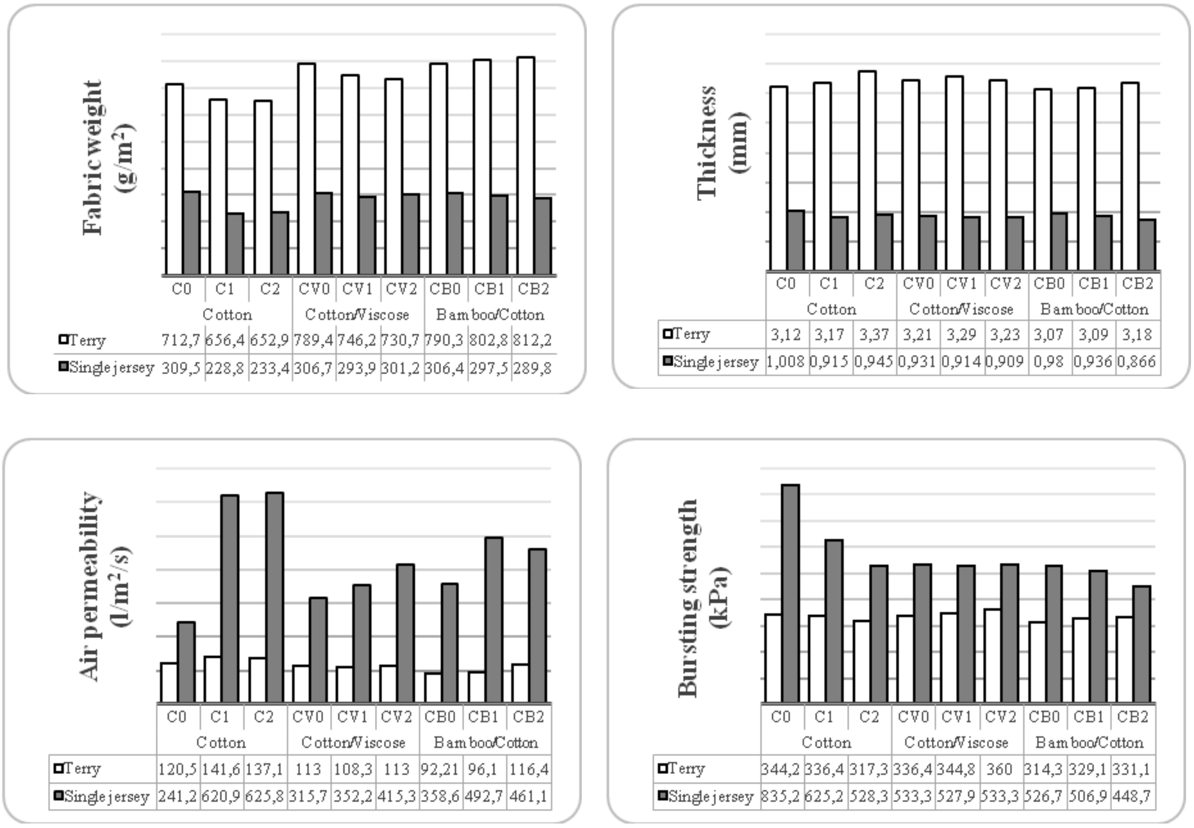
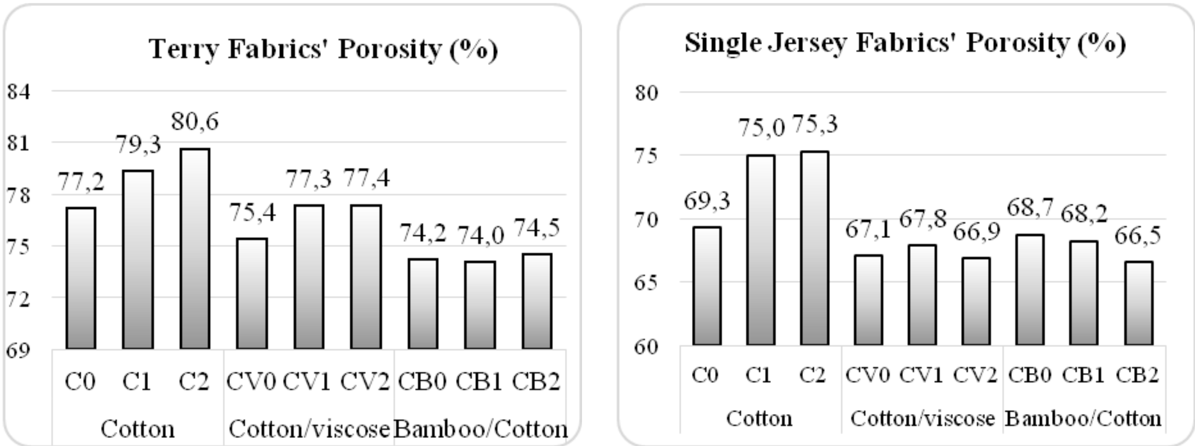


Fig. 4. (a) Fabric weight, (b) thickness, (c) air permeability, and (d) bursting strength values of the samples.



(a) **(b)**

Fig. 5. The calculated fabric porosity (%) of terry (a) and single jersey (b) fabrics.

Single Jersey Fabric Test Results

Fabric weight. thickness. porosity. air permeability. and bursting strength

For cotton and bamboo-cotton blend fabrics, the weight and thickness values of the fabrics with loose yarn structure are lower than the reference fabric (Fig. 4 a, b) and the difference between them is statistically significant (Table 4). However, no statistically significant difference was observed for cotton-viscose fabrics. Similar results for single jersey fabric's weight have been reported in the literature [10, 18]. On the other hand, Celep and Yüksekkaya [38] reported that the thickness of 100% cotton reference fabric was lower than that of 100% cotton knitted fabrics with a loose yarn structure; whereas no significant differences were observed in fabric weight. This phenomenon is thought to be due to the difference in the migration tendencies of different fibers, after washing.

The air permeability values of fabrics knitted with core-spun yarns were higher than those of reference yarns, and the differences were statistically significant (Fig. 4-c).

Since the single jersey structure is much looser and has less fabric weight and thickness, air permeability values are higher than those of terry fabrics are. In terry fabrics, yarn density per unit area is higher due to the presence of piles, which adversely affects air permeability. The effect of fabric construction is more dominant than fiber type and yarn structure on air permeability.

The bursting strength values of the single jersey fabrics with reference yarns were the highest (Fig. 4-d). For cotton and bamboo/cotton fabrics, the bursting strength decreased with loose yarn structures. For the cotton/viscose fabrics, however, the effect of the yarn structure on the knitted fabric's bursting strength was insignificant.

Among 100% cotton fabrics, as the compactness of yarn structure decreased by using core material, the porosity value of the fabric increased (Fig. 5). Porosity was decreased with regenerated cellulose fibers, compared to 100% cotton fabrics. Among regenerated cellulosic fiber-containing fabrics, the fabric weight and thickness decreased resulting in increasing air permeability and decreased porosity, due to using core-spun yarns.

Wicking

One crucial factor influencing physiological comfort is moisture/liquid transport in textiles. Materials that quickly transport moisture/liquid away from the skin's surface provide a better wearing experience by keeping the skin dry. The component yarns are responsible for most of the wicking [49] in capillary flow through textiles.

Wicking is the spontaneous movement of fluids along textile fibers in textile products. It is the diffusion of a liquid from the area where it is dense to other areas. In yarns, the arrangement and orientation of the fibers affect the liquid transport properties of the yarns due to the continuity of the capillaries. For this reason, yarns with different intra-yarn porosities are thought to affect the wicking properties of fabrics. As mentioned previously, the wicking property of single jersey fabrics was investigated by the capillary rise test, but all fabrics rapidly have the same capillary rise. Therefore, for detailed analyses, MMT was used to test the moisture management properties of single jersey fabrics.

Table 5 and Table 6 show the results of the moisture management test and statistical results for the single jersey fabrics, respectively. According to the single-jersey fabrics' results, it was found that the difference between the values of the top absorption rate, the bottom absorption rate, and the bottom fabric spreading rate was statistically significant (Table 6).

Absorption Rate (Top and Bottom) (%/s) refers to the rate at which liquid is absorbed by the top and bottom layers during the test. While the bottom spreading speed varied significantly among fabric groups, the top spreading speed did not show statistical significance. Cotton fabrics demonstrated better moisture management compared to fabrics made from bamboo and viscose, which retain more moisture due to their higher moisture regain capacities [53].

Table 5. Moisture management properties of the fabrics regarding yarn property.

	C0	C1	C2	CV0	CV1	CV2	CB0	CB1	CB2
Wetting time top (sec)	4.38	3.16	3.48	4.59	3.61	3.58	3.24	3.77	3.64
Wetting time bottom (sec)	4.47	3.51	3.85	5.10	3.88	4.01	3.56	3.61	3.84
Top max wetted radius (mm)	13.33	18.33	15	13.33	15	15	10	15	15
Bottom max wetted radius (mm)	15	18.33	15	13.33	15	15	13.33	15	15
Top absorption rate (%/sec)	38.01	47.22	39.2	46.66	50.03	43.11	54.39	47.60	47.44
Bottom absorption rate (%/sec)	40.93	48.42	40.14	31.78	39.32	40.86	39.35	39.31	39.96
Top spreading speed (mm/sec)	2.09	3.28	2.81	2.18	2.58	2.55	2.68	2.54	2.55
Bottom spreading speed (mm/sec)	2.17	3.11	2.69	1.98	2.46	2.34	2.49	2.48	2.41
Accumulative one-way transport Index (AOTI) (%)	86.39	49	42.49	-113.68	-45.81	29.23	-38.68	-0.61	-9.04
OMMC*	0.34(P)	0.39(P)	0.33(P)	0.14(VP)	0.21(P)	0.29(P)	0.21 P)	0.26(P)	0.24(P)

*For OMMC values: 0–0.2: very poor (VP). 0.2–0.4: poor (P). 0.4–0.6: good (G). 0.6–0.8: very good (VG). >0.8: excellent (E) (The AATCC Standard 195)

Table 6. Analysis of variance of MMT test results.

	Wetting time top	Wetting time bottom	Top absorption rate	Bottom absorption rate	Top spreading speed	Bottom spreading speed
p-value	0.459	0.343	0.00*	0.00*	0.17	0.07*

*Significant for $\alpha = 0.05$.

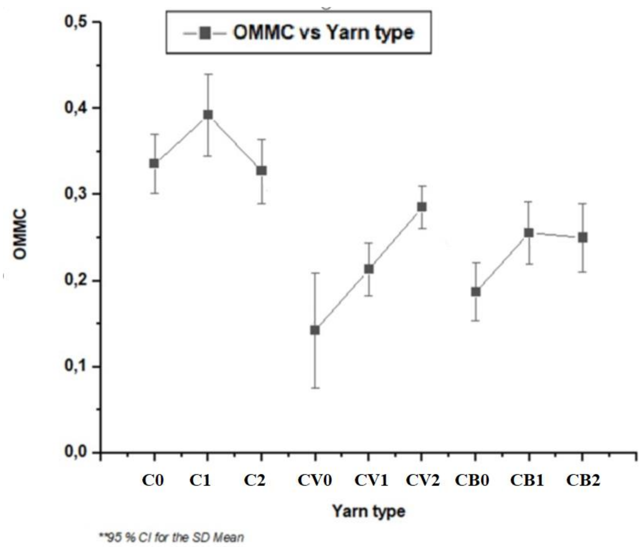


Fig. 6. OMMC values were obtained from MMT test results

The OMMC value calculated by the device represents the moisture-drying rate of the fabric, and these values were assessed according to the AATCC 195 Standard (Table 5) [52]. The total transport capacity increases with increasing OMMC value. Cotton fabrics were found to have the best moisture management among all fabric types in parallel with the literature [56]. The total moisture management value (OMMC) first increased slightly for the knitted with C1 yarn compared to reference cotton fabric. However, the OMMC value of the fabric knitted using C2 yarn is lower than that with C1 yarn. Since the fabric knitted with C2 yarn has a looser yarn structure, the fabric has a lower weight and slightly increased thickness value.

Fabrics made from cotton/viscose and bamboo/cotton exhibited poorer moisture management, particularly the cotton/viscose blend. In cotton/viscose and bamboo/cotton fabrics, it can also be observed that the porous and looser yarn structure improves moisture management (Fig. 6). At this point, not only the fabric structure is effective, but also the structure within the yarns in fabric and within the fibers in the yarn is an important factor. It has been stated that the total porosity of the fabric consists of three components: intra-fiber porosity, intra-yarn porosity, which covers the space between the fibers in the yarn, and inter-yarn porosity, which includes the empty volume created by the different intersections of the yarns in the fabric [52]. In other words, while 100% cotton fabrics are absorbent and conductive, viscose and bamboo content fabrics are less likely to transfer moisture to the reverse side.

Cotton fabrics also possessed significantly higher AOTI values, indicating their ability to transfer moisture efficiently. The AOTI value indicates that the fabric can easily and quickly transfer liquids from the outer surface to the inside [10]. In contrast, viscose and bamboo fabrics retained moisture, resulting in a damp feeling. Excessive moisture absorption can also be problematic, as a material that absorbs more moisture may result in stickiness and dampness due to reduced moisture distribution across the fabric surface. This could explain why the OMMC of cellulosic fiber-containing fabrics is relatively lower than that of cotton fabrics [56]. These findings suggest that, despite the popularity of cellulosic fibers, 100% cotton socks may provide superior comfort in moisture management.

Terry Fabric Test Results

Fabric weight. thickness. porosity. air permeability. and bursting strength

For cotton and cotton/viscose terry fabrics, the weight of fabrics made with core-spun yarns was statistically significantly lower than that of fabrics made with reference ring yarns. For both cotton and cotton/viscose terry fabrics, the weight of fabrics knitted with core-spun yarns decreased after washing. However, this trend did not hold for bamboo/cotton fabrics. Notably, the highest weight values for bamboo/cotton terry fabrics were observed in fabrics knitted with CB2 yarn, in contrast to single jersey fabrics. The greater the distance between the fibers in the yarn, the more the fibers migrated towards the center, resulting in a looser yarn structure after the filament was removed by washing. These findings are likely related to the high bamboo content in bamboo/cotton fabrics compared to other fabric types. Bamboo fibers exhibit greater shrinkage after washing compared to cotton fibers due to their higher moisture absorption capacity [57. 58]. As bamboo fibers have a higher shrinkage ratio, this effect became more pronounced as the amount of bamboo in the structure increased. Consequently, the loose yarn structure used in the pile of bamboo/cotton fabrics experiences more shrinkage after washing than that of cotton and cotton/viscose fabrics.

Among the terry fabrics, the thickness of terry fabrics with reference yarns was the lowest in contrast to single jersey fabrics. It was found that the difference between fabrics knitted with core-spun yarns and reference yarns was statistically significant. The thickness of terry fabrics increases with looser yarn structures, except for cotton/viscose fabrics. The difference in thickness of cotton/viscose fabrics knitted with core-spun yarns was not statistically significant. When looser yarns were used for the pile of terry fabrics, the thickness of the fabric increased slightly due to the less compact structure compared to fabrics made with reference yarns.

In cotton fabrics, porosity significantly increases using C1 and C2 yarns (Fig. a). While cotton-viscose fabrics show a slight porosity increase compared to the reference fabric, bamboo-cotton fabrics exhibit no change. This behavior is attributed to the shrinkage characteristics of regenerated cellulose fibers after washing, as previously discussed.

Air permeability analysis revealed that fabrics made with reference yarns generally exhibited the lowest values, except for cotton/viscose terry fabrics, where yarn structure showed no statistically significant effect on air permeability. Microscope images of washed cotton/viscose fabrics indicated similar structural appearances. In contrast, cotton terry fabrics produced with core-spun yarns demonstrated significantly higher air permeability than those with reference yarns, attributed to the looser structure resulting from removing core filaments. Variations in core ratio were not statistically significant (Table 7). The enhanced air permeability is likely due to the looser yarn structure and fiber migration during washing, increasing air gaps within the fabric (Fig. 4). Cotton fabrics have higher air permeability values than others. The behavior of single jersey and terry fabrics varied depending on the composition of the sheath material. The behavior of single jersey and terry fabrics varied based on the composition of the sheath material.

There is no statistically significant difference between the bursting strength values for all terry fabrics knitted with different raw materials. Therefore, it can be concluded from the test results that the porous, and looser structure of the terry fabric has no negative influence on the bursting strength of the fabrics.

Hydrophilicity

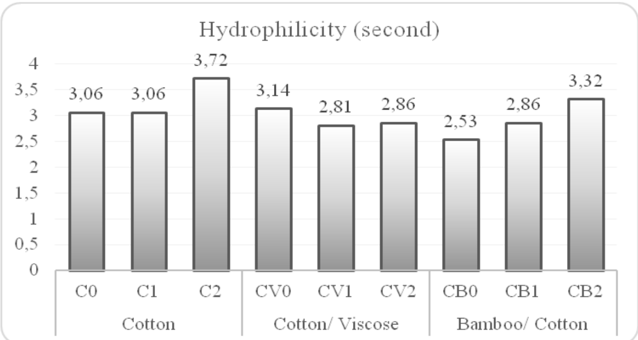


Fig. 7. Hydrophilicity test results for terry fabrics (second).

Figure 7 illustrates the average immersion (sinking) times of samples, reflecting fabric hydrophilicity. For 100% cotton fabrics, decreasing yarn compactness increased fabric porosity, leading to higher air permeability and hydrophilicity (water absorbency) values (Fig. 7). When regenerated cellulose fibers were incorporated into the yarn structure, different trends were observed with the influence of the fabric knitting structure. When 50/50 cotton/viscose was used in pile yarns in terry fabrics, a slight decrease in hydrophilicity value was observed, although porosity slightly increased and weight decreased for looser yarn structures used. As the proportion of regenerated cellulosic fibers increased in the yarn, fabric weight and thickness increased slightly due to the looser yarn structure in the pile, while air permeability and hydrophilicity increased.

Hydrophilicity analysis revealed all terry fabrics (cotton and bamboo/cotton) to be hydrophilic, with the highest values observed in fabrics made from highly porous yarns (Fig. 6). Statistical analysis (SNK test) confirmed significant differences in hydrophilicity between fabrics with reference yarns and those with more open structures core-spun yarns (more loose and slack). However, no significant differences were found between reference yarn fabrics and those using C1 and CB1 yarns.

5. Conclusions

The study aims to design yarns and fabrics for sock production using yarns with different yarn structures (loose-compact). For this purpose, yarns with different core/sheath ratios were produced with various sheath materials such as cotton, cotton/viscose, and bamboo/cotton. While PVA yarn was used in previous studies, an environmentally friendly water-soluble fiber was used as the core material in this study. The thickness of the core material was changed to obtain a different yarn structure. The yarns used in the production of socks are spun into hollow yarn using the core yarn production technique. However, as can be seen in the SEM images (Figure 1), after removing the core material, the emptied area was closed due to the migration of the surrounding fibers. Instead of the hollow yarn structure, yarns with different yarn structures (loose-compact) were obtained. The performance characteristics of these yarns in single jersey and terry structures were investigated. In addition, the weight, thickness, air permeability, bursting strength, and water absorption properties of the fabrics were measured, as these are the primary expected performance parameters for socks. The effects of loose yarn structure on fabric properties in terry and single-jersey fabric structures were found to be different. In addition, when different raw materials were used, the effect of loose-structured yarns on fabric properties showed different trends.

Table 7. The effect of yarn structure on the air permeability of terry fabrics (SNK test- Subset for alpha = 0.05).

	Subsets				
	Cotton		Cotton/ viscose	Bamboo/cotton	
	1	2	1	1	2
Reference yarns	120.5		113	92.21	
C1/CV1/CB1		141.6	108.3	96.1	
C2/CV2/CB2		137.1	113		116.4
Sign. (p-value)	1	0.422	0.295	0.216	1

This study highlights the interactions between yarn structure, fiber type, and fabric construction on key physical properties such as porosity, weight, thickness, air permeability, and bursting strength.

- Removing the core material resulted in a looser, more open yarn structure with increased porosity. Sheath fibers collapsed inward, partially filling the void left by the core.
- Looser yarn structures showed reduced tenacity and breaking elongation (%) compared to reference yarns. No significant differences were found between the elongation values of cotton and cotton/viscose yarns, which is consistent with previous studies. Yarn structure did not have a statistically significant effect on tensile strength or breaking elongation (%).
- In 100% cotton single jersey fabrics, decreasing yarn compactness using core materials led to increased porosity. Fabrics with regenerated fibers exhibited lower porosity compared to 100% cotton fabrics. Using loose yarns reduced fabric weight and thickness, increasing air permeability and decreased porosity.
- For cotton/viscose fabrics, yarn structure (loose or compact) did not significantly affect fabric weight, aligning with findings from previous studies.
- Single jersey fabrics knitted with loose yarns exhibited higher air permeability than those with reference yarns, with statistically significant differences [20, 54].
- Single jersey fabrics made with reference yarns showed the highest bursting strength values. For cotton and bamboo/cotton fabrics, bursting strength decreased with looser yarn structures.
- According to the results of the moisture management test, cotton single jersey fabrics exhibited the best moisture management properties, consistent with the literature. Cotton/viscose and bamboo/cotton fabrics had poorer moisture management, with standard ring cotton/viscose fabrics performing the worst. However, porous and looser yarn structures improved moisture management in blended fabrics, influenced by intra-fiber, intra-yarn, and inter-yarn porosity. The effect of the raw material type on these values is more dominant than the yarn structure, viscose and bamboo fabrics lead to a wet and sticky sensation because of trapping moisture within their structure [55]. While cotton fabrics effectively absorb and transfer moisture, viscose and bamboo fabrics are less efficient because of trap the moisture within the structure.
- Among terry fabrics. reference yarns resulted in the lowest thickness values, unlike single jersey fabrics. Looser yarns in terry fabric piles led to slightly increased thickness due to a less compact structure.
- Fabrics made with reference yarns generally had the lowest air permeability values. Cotton terry fabrics with loose yarns exhibited higher air permeability, attributed to the looser yarn structure and repositioning of sheath fibers after washing. The degree of core ratio did not significantly affect air permeability. but the looser yarn structure increased air gaps, enhancing permeability.
- Hydrophilicity analysis revealed terry fabrics (cotton and bamboo/cotton), decreasing pile yarn compactness increased fabric porosity, leading to higher air permeability and hydrophilicity (water absorbency) values. In parallel with the results of Uttam et al. [38], the pore diameter, which is responsible for capillarity. decreases with compact yarn structure and increases wicking performance. In yarn structures produced from staple fibers, pore size, pore size distribution, interconnection of these pores, and pore volume are the parameters that affect capillary liquid transmission [8].

In conclusion; bamboo fibers, with their higher moisture absorption and shrinkage properties, significantly influenced the behavior of bamboo/cotton terry fabrics, particularly in terms of weight and thickness. Cotton fabrics generally demonstrated higher air permeability compared to other fabric types. Single jersey and terry fabrics showed distinct behavior depending on the yarn structure and sheath materials used. Despite the growing popularity of viscose and bamboo yarns for socks, this study found 100% cotton socks to be more comfortable for moisture transfer. For this reason, using looser yarns in both terry and single jersey fabric structures will improve the comfort properties of the product without adversely affecting its mechanical properties.

REFERENCES

1. Li, Y., Zhu, Q., Yeung, K.W. 2002. Influence of Thickness and Porosity on Coupled Heat and Liquid Moisture Transfer in Porous Textiles. *Textile Research Journal*, 72 (5), 435-446.
2. Li, Y., Zhu, Q. 2003. Simultaneous Heat and Moisture Transfer with Moisture Sorption, Condensation and Capillary Liquid Diffusion in Porous Textiles. *Textile Research Journal*, 73(6), 515-524.
3. Perwuelz, A., Casetta, M., Caze, C. 2001. Liquid organization during capillary rise in yarns-influence of yarn torsion, *Polymer Testing*, Vol. 20(5), 553-561.
4. Doakhan, S., Hosseini, R.S., Gharah,A.A., Mortazavi, S.M. 2007. Capillary rise in core-spun yarn. *Iranian Polymer Journal*.16 (6), 397-408.
5. Ramkumar, S.S., Purushothaman, A., Hake, K.D., McAlister, D.A. 2007. Relationship between Cotton Varieties and Moisture Vapor Transport of Knitted Fabrics. *Journal of Engineered Fibers and Fabric*, 2 (4), 10-18.
6. Dai, X.Q., Imamura, R., Liu, G.L., Zhou, F.P. 2008. Effect of Moisture Transport on Microclimate Under T-shirts. *European Journal of Applied Physiology*, 104 (2), 337-340.
7. Hu, J., Li, Y., Yeung, K.W., Wong, A.S.W., Xu, W. 2005.Moisture Management Tester: A Method to Characterize Fabric Liquid Moisture Management Properties. *Textile Research Journal*, Vol. 75 (1), 57-62.

8. Ozdil, N., Supuren, G., Ozcelik, Pruchova G.J.A. 2009. A study on the moisture transport properties of the cotton knitted fabrics in single jersey structure. *Tekstil ve Konfeksiyon*, Vol. 19 (3), 218-223.

9. Öner, E., Atasağun,H.G., Okur, A., Beden, A.R., Durur, G. 2013. Evaluation of moisture management properties on knitted fabrics. *The Journal of The Textile Institute*, Vol. 104 (7), 699-707, DOI: 10.1080/00405000.2012.752895

10. Baltušnikaitė, J., Abraitienė, A., Stygienė, L., Krauledas, S., Rubežienė, V., Varnaitė-Žuravliova, S. 2014. Investigation of moisture transport properties of knitted materials intended for warm underwear. *Fibres & Textiles in Eastern Europe*,22 (4) (106). 93–100.

11. Chen, Q., Tang, K.M., Ma, P., Jiang, G. 2016. Evaluation of water absorption and transport properties of weft knitted polyester fabrics by spontaneous uptake water transport tester and conventional test methods. *Fibers and Polymers*, 17 (8), 1287–1295. https://doi.org/10.1007/s12221-016-6454-3.

12. Mukhopadhyay, A., Ishtiaque, S.M., Uttarn, D. 2011. Impact of structural variations in hollow yarn on heat and moisture transport properties of fabrics. *The Journal of The Textile Institute*, Vol. 102 (8), 700-712.

13. Chandrasekaran, V., Senthilkumar, P., Sakthivel, J.C. 2018. Study on moisture management properties of micro-pore ring-spun viscose yarn-plated knitted fabrics. *The Journal of The Textile Institute*, 109(11), 1458–1464, https://doi.org/10.1080/00405000.2018.1423884

14. Ozdil, N. 2008. A Study on Thermal Comfort Properties of the Socks. *Tekstil ve Konfeksiyon*, Volume 2 154-158.

15. Vasanth Kumar D., Raja D. 2021. Study of thermal comfort properties on socks made from recycled polyester/virgin cotton and its blends, *Fibers and Polymers*. 22. 841-846.

16. Cimilli S., Uyar Nergis B., et al. 2009. A Comparative Study of Some Comfort-related Properties of Socks of Different Fiber Types, *Textile Research Journal*, 80 (10). 948-957.

17. Čiukas R., Abramavičiūtė J. 2010. Investigation of the Air Permeability of Socks Knitted from Yarns with Peculiar Properties, *Fibres & Textiles in Eastern Europe*, Vol. 18, 1 (78). 84-88.

18. Demiroz Gun A., Alan G. Sevkan Macit, G. A.2016. Thermal properties of socks made from reclaimed fibre, *The Journal of the Textile Institute*, 107(9). 1112-1121.

19. Morgil, Y. 2015. Thermal Comfort Properties of Terry Knitting Socks. 2015. Master of Science Thesis, Science Engineering and Technology Institute, Istanbul Technical University. Istanbul, Türkiye.

20. Anas M.S., Abaas A., et al.. 2023. A study on the effect of material type, structure tightness and finishing process on the physical and thermo-physiological properties of sandwich terry socks for winter wear, *Journal of Engineered Fibers and Fabrics.* 18: 1–14, https://doi.org/10.1177/15589250231153398

21. Abbas A., Anas M.S., Azam Z. 2023. In vitro experimental study on effect of fiber denier, yarn doubling, and specialty treatments on physical and thermal behaviors of knitted sports socks, *Journal of Engineered Fibers and Fabrics*, 18: 1–14, https://doi.org/10.1177/15589250221148917

22. Khalil A., Hussain T., Ahmad N., Jamsaid H. 2024. Multi-criteria optimization of sports compression socks using Taguchi-VIKOR statistical approach, *Journal of Engineered Fibers and Fabrics*. 19: 1–15, https://doi.org/10.1177/15589250241248762

23. Cimilli Duru S., Candan C. 2019. Chapter 23: Some Comfort Properties of Terry Knitted Fabrics Made From Cotton/Polyester Blend, *Engineering Research Papers*, Editors: A. Gunday, E. Pehlivan, M.R. Minaz, Gece Publishing. 409-422. ISBN 978-625-7958-55-4.

24. Karahan M., Eren R. 2006. Experimental Investigation of the Effect of Fabric Construction on Static Water Absorption in Terry Fabrics. *Fibres & Textiles in Eastern Europe*. 14 (2) 59-63.

25. Karahan M. 2007. Experimental Investigation of the Effect of Fabric Construction on Dynamic Water Absorption in Terry Fabrics. *Fibres&Textiles in Eastern Europe*, Vol. 15 (3) (62) 74-80.

26. Durur G. Oner E. 2013. The Comfort Properties of the Terry Towels Made of Cotton and Polypropylene Yarns, *Journal of Engineered Fibers and Fabrics*, 8 (2) https://journals.sagepub.com /doi/pdf/10.1177/155892501300800201.

27. Vuruşkan D., Babaarslan O., Ilhan I. 2013. Modification of Ring Spinning Machine for Producing Core Yarn Containing Elastane, *Tekstil ve Mühendis*, 20 (89) 1-10. DOI: 10.7216/ 130075992013208901

28. Nergis B. U. 2007. Influence of core yarn properties on pile loss in chenille plain knitted fabrics, *Textile Research Journa*l, Vol. 73(12), pp. 1052-1056, DOI:10.1177/004051750307301204

29. Sarıoğlu E., Babaarslan O. Ertek Avcı, M. 2018. Effect of Filament Fineness on Composite Yarn Residual Torque, *Autex Research Journal*, 18 (1). 7-12.

30. Alasehirli G. 2009. An investigation of hollow yarn manufacturing techniques on ring spinning machine and evaluation of yarn properties, Süleyman Demirel University Graduate School of Applied and Natural Sciences.

31. Celeb G., Dayik M. 2009. Hollow yarns and production methods, *Electronic Journal of Textile Technologies*, 3 (2). 50-57.

32. Pourahmad A., Johari M.S. 2011. Comparison of the properties of Ring, Solo, and Siro core-spun yarns, *Journal of the Textile Institute*, 102 (6) 540-547.

33. Ishtiaque S.M., Das A., Singh R.P. 2008. Packing of micro-porous yarns: Part I. Optimization of yarn characteristics, *The Journal of the Textile Institute*, 99 (2). 147-155.

34. Merati A.A., Okamura M. 2000. Hollow Yarn in Friction Spinning Part I: Tensile Properties of Hollow Yarn, *Textile Research Journal*, 70(12). 1070-1076.

35. Merati A.A., Okamura M. 2001. Hollow yarn in friction spinning. Part II: Yarn structure and deformation under axial tension and lateral forces, *Textile Research Journal,* 71(5). 454-458.

36. Merati A.A., Okamura M. 2003. Limits of Hollow Yarn in Friction Spinning. *Textile Research Journal*, 73 (6). 496-502.

37. Ma H.Y., Xia Z.P. 2006. Relationships between Different Preparations of Cotton Hollow Yarn and Water Soluble PVA Extraction, *Journal of Donghua University* (Eng. Ed.), 23(3).

38. Uttam D., Mukhopadhyay A., Ishtiaque S.M. 2013. Modelling to predict thermophysiological properties of hollow/microporous yarn fabrics. *Journal of the Textile Institute*. 104(4). 407-413.

39. Aytac I., Gurkan Unal P. 2018. The effect of core-sheath proportion on the characteristics of hollow yarns: part I mechanical properties. *The Journal of The Textile Institute*. 109 (7). 967-974, DOI: 10.1080/00405000.2017.1394156.

40. Aytac I., Gurkan Unal P. 2018. The effect of core-sheath proportion on the characteristics of fabrics produced with hollow yarns: part II comfort and mechanical properties, *The Journal of The Textile Institute.* 109 (7). 975-982. DOI: 10.1080/00405000.2017.1394783.

41. Celep G., Yuksekkaya M.E. 2017. Comparison of thermal comfort properties of single jersey fabrics produced by hollow yarns with different hollowness ratio. *The Journal of The Textile Institute*, 108 (2). 165-171. DOI: 10.1080/00405000.2016.1160763.

42. Gurkan Unal P., Ureyen M.E. 2017. Permeability properties of single jersey fabrics made of hollow yarns. *The Journal of the Textile Institute.* Vol. 108 (11).1957-1965. DOI: 10.1080/00405000.2017.1302634.

43. Andrysiak J., Sikorski K., Wilk E., Matusiak M. 2014. Investigation of an innovative "Cotton Hollow" yarn. *Fibres & Textiles in Eastern Europe.* 22, 5 (107). 33-37.

44. Senthilkumar P. 2018. Comfort characteristics of cotton hollow yarn knitted fabrics: Part 3-Structural properties. *Man-Made Textiles in India*. 46(5).

45. Gungor Turkmen B., Celik P., Sehit H., Bedez Ute T. 2023. The effects of hollow yarn and fabric structure on permeability and moisture management properties of woven fabrics, *The Journal of The Textile Institute*. April. DOI:10.1080/00405000.2023.2201109.

46. Gungor Turkmen B., Celik P., Sehit H., Bedez Ute T. 2023. Investigation of the effects of hollow yarn structure and woven fabric construction on fabric performance: mechanical properties. *The Journal of The Textile Institute.* April. DOI: 10.1080/00405000.2023.2196044.

47. Das A., Ishtiaque S.M. Singh, R. P.2009. Packing of micro-porous yarns. Part II: Optimization of fabric characteristics. *Journal of the Textile Institute*. 100 (3). 207–217. https://doi.org/10.1080/00405000701559917

48. Ala D.M. 2021. An Experimental Study on Selected Performance Properties of 100% Cotton Terry Fabrics *Tekstil ve Konfeksiyon*. 31 (1). 43-52.

49. Turan R. B., Okur, A. 2008. Air Permeability of Fabrics. *Tekstil ve Mühendis*. 15 (72). 16-25.

50. Benltoufa S., Fayala F., Ben Nasrallah S.2008. Capillary rise in macro and micro pores of jersey knitting structure. *Journal of Engineered Fibers and Fabrics*. 3(3). 155892500800300305.

51. Y. Li, W. Xu, K.W. Yeung, Moisture Management of Textiles, 2000, U.S. patent 6,499,338 B2.

52. Balci Kiliç, G. 2022. A Comparative Investigation of Transfer, Permeability and Porosity Properties of Single Jersey Knitted Fabrics. *Tekstil ve Mühendis*. 29:128. 238-248.

53. Büyükakıncı, B. Y. 2010. Investigation of the internal structure of regenerated bamboo fiber. *Tekstil ve Konfeksiyon*. 20(4). 277-283.

54. Moghassem A.R., Gharehaghaji A.A. 2009. Redistribution of fibers in the structure of hollow ring yarns. *International Journal of Engineering Transactions B: Applications*. 22 (2). 197-204.

55. M.Kayri, The Multiple Comparison (Post-Hoc) Techniques to Determine the Difference Between Groups in Researches, Fırat University Journal of Social Science, (2009) 19 (1): 51-64

56. Hussain, U., Bin YounisF., et al.2015. Comfort and Mechanical Properties of Polyester/Bamboo and Polyester/Cotton Blended Knitted Fabric, *Journal of Engineered Fibers and Fabrics*. 10(2):61-69.

57. Erdumlu, N., Ozipek, B. 2008. Investigation of regenerated bamboo fibre and yarn characteristics. *Fibres & Textiles in Eastern Europe*. 16(4), 69.

58. Ahmad, I., Farooq, A., Baig, S. A., Rashid, M. F. 2012. Quality parameters analysis of ring spun yarns made from different blends of bamboo and cotton fibres. *Journal of Quality and Technology management*. (1), 1-12.