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Comfort behaviour of woven bamboo-cotton ring and MJS yarn fabrics

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The thermal comfort characteristics of light weight bamboo-cotton blended apparel fabrics have been studied in relation to fibre composition, yarn linear density and spinning mode. The experimental results show that a denser fabric has higher thermal insulation, higher absorbency and yields higher air and water vapour permeabilities. The fabrics made from the MJS yarns display considerably higher air and water vapour permeabilities, higher thermal resistance and lower wickability as compared to their ring-spun counterparts. With increasing second jet pressure, the air and water vapour permeabilities improve initially but deteriorate thereafter as the second jet pressure is further raised beyond a particular level. Analysis of the fibre-mix reveals that the 70:30 bamboo-cotton fabrics are relatively less air and water vapour permeable, less thermal resistant and exhibit higher wickability than their 48:52 bamboo-cotton couples.

Keywords: Air permeability, Clothing comfort, Jet-spun yarn, Ring-spun yarn, Thermal resistance, Water vapour permeability, Wicking

1 Introduction

Bamboo fibre has been used in various applications such as building and construction, decoration, slope maintenance and high performance composites for the past many years. Regenerated bamboo fibre has characteristic mechanical properties of superior tensile strength, excellent UV protection, antibacterial and biodegradable characteristics, high moisture absorption, softness, brightness and high flexibility under flexible and compressive loads. Although there has been some research on the mechanical properties of bamboo fibre[1-4], few reports[5] have been published on the performance of bamboo fabrics, especially in comparison with ramie fabrics. With its high moisture absorption capacity, breathability and fast drying behaviour, regenerated bamboo cellulose fibre ensures excellent comfort in various applications. Currently, regenerated bamboo fibre is used in intimate apparels, hygienic products and sanitary materials, nonwovens and home furnishings. The present paper reports study on the comfort characteristics of bamboo-cotton ring and MJS yarn fabrics in relation to blend composition, yarn geometry, yarn linear density and second nozzle pressure. Such studies would be very useful for facilitating the understanding of in-depth relationships between processing factors and comfort aspects of woven bamboo-cotton fabrics, as well as broaden applications of these materials for textiles.

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2 Materials and Methods

2.1 Preparation of Yarn and Fabric Samples

Two sets of 14.7 and 19.6 tex yarns were spun from two different blends of bamboo and cotton fibres on Murata air-jet spinner. The blending of bamboo and cotton fibres, having the specifications as given in Table 1, was carried out on the draw frame. Each fibre was processed on a Lakshmi Rieters' blow room line and carded on a MMC card. The carded slivers were drawn thrice on a Lakshmi Rieters' drawframe DO/2S. The linear densities of drawn slivers were adjusted to 3.1 and 4.0 ktex. The slivers were spun into yarns on Murata air-jet spinner 802 MJS operating at 180 m/min. For ring yarns, the drawn slivers were converted into roves of 0.50 and 0.70 ktex, and the roves were then fed to a Lakshmi Rieters' ring frame G5/1 using spindle speed of 14500 rpm. Sixteen plain woven fabrics were produced with R 11.8/2 tex 65:35 polyester-viscose yarn as warp and various other yarns

Table 1—Specifications of bamboo and cotton fibres

Fibre	Length mm	Linear density dtex	Tenacity cN/tex	Breaking extension, %
Bamboo	40	1.55	30.5	30.2
Cotton	35.5[a]	1.62	29.2	8.6

[a]2.5% span length.

as filling. The woven fabrics having the specifications as given in Table 2, were produced on a Texmaco loom and had approximately 22 ends/cm; and 22 and 25 picks/cm for 19.6 and 11.7 tex yarns respectively.

2.2 Finishing Treatment

Greige fabrics were washed and scoured with caustic (1.5 g/L), soda (1.5 g/L) and non-ionic detergent (1 g/L) at 90°C for 90 min. After scouring, the samples were thoroughly washed with cold and hot water for 15 min each to remove adhered chemicals from each fabric, neutralized with acetic acid (2 g/L), washed thoroughly and dried at 90°C.

2.3 Test Methods

2.3.1 Yarn Properties

All the yarns were tested for hairiness on Zweigles hairiness meter (Model G 565). The yarn diameter was measured by Leica Q500 MC at 100 randomly selected places along the length of the yarn. A sufficient length of the yarn was covered to take care of any variation.

2.3.2 Fabric Properties

2.3.2.1 Air Permeability

Air permeability tests were conducted on Prolific air permeabilty tester according to ASTM standard D737-96. The conditioned test specimen was centrally placed between adapter disc and lower grip and the sufficient tension was applied on the fabric to eliminate wrinkles. Adequate holding pressure was applied so as to prevent slippage of the fabric and also to eliminate the leakage of air through the gripping faces. The power supply to the equipment and vacuum pump was switched-on and the flow adjusting valve was slowly opened and adjusted to increase the air-flow till the desired pressure drop was obtained on the manometer. Recorded air-flow was divided by the exposed area of the test specimen. Exposed area of test specimen was 10 cm^2 under the pressure drop of 10 mm of water column.

2.3.2.2 Water- vapour Transmission

Water-vapour permeability of fabrics was determined by means of the Permetest tester. The instrument measures the heat flow caused by the evaporation of water passing through the tested specimen. The fabric sample was spread on the measuring head and thereafter water was injected on the measuring head. Evaporation took place under standard atmospheric conditions of 65% RH and 20° C temperature. As the heat lost from the wet measuring head depends upon the permeability characteristics of the fabric, the output voltage with a fabric would be different as compared to the bare measuring head. The relative water vapour permeability is given by the following expression:

$$\text{Relative water vapour permeability (\%)} = [U_1/U_2] \times 100$$

where U_1 and U_2 are the output voltage with and without fabric on the measuring head.

2.3.2.3 Wickability

The wickabililty of fabrics was determined by the vertical wicking test as per TAPCC standard. Here, conditioned fabric specimen (20 cm × 2.5 cm) cut

Table 2—Characteristics of bamboo- cotton ring and MJS yarns

Yarn ref. no.	Yarn type	Yarn linear density, tex	Blend ratio (Bamboo/Cotton)	Twisting jet pressure, kg/cm^2	Diameter mm	Hair/100m	Wraps/cm
S1	MJS	19.6	70:30	4.0	0.179	1085	10.1
S2	MJS	19.6	70:30	4.5	0.159	863	15.0
S3	MJS	19.6	70:30	5.5	0.178	983	14.1
S4	MJS	19.6	48:52	4.0	0.214	854	9.8
S5	MJS	19.6	48:52	4.5	0.178	338	14.4
S6	MJS	19.6	48:52	5.5	0.199	358	12.3
S7	MJS	14.7	70:30	4.0	0.150	782	12.1
S8	MJS	14.7	70:30	4.5	0.115	197	16.7
S9	MJS	14.7	70:30	5.5	0.129	431	14.8
S10	MJS	14.7	48:52	4.0	0.152	653	11.5
S11	MJS	14.7	48:52	4.5	0.133	297	15.7
S12	MJS	14.7	48:52	5.5	0.138	405	14.1
S13	Ring	19.6	70:30	-	0.166	1492	-
S14	Ring	19.6	48:52	-	0.177	1084	-
S15	Ring	14.7	70:30	-	0.133	1080	-
S16	Ring	14.7	48:52	-	0.158	857	-

along the weft direction was hung vertically on a ring holder. The specimen was then dipped in water solution of 2 g/L cold brand reactive dye up to a mark made at a distance of 3 cm from the fabric edge. The vertical wickability is then expressed as the wicking height in cm noted after a time interval of 15 min.

2.3.2.4 Thermal Insulation

Thermal insulation of the fabric was measured on Permetest tester under non-isothermal conditions. The heat flow rate was measured at the measuring head with and without fabric specimen. As the heat lost from the dry measuring head depends upon the thermal characteristics of the fabric, the corresponding output voltage would be different when measured in presence of a fabric as compared to the one measured with bare measuring head. The thermal resistance (R) was calculated using the following expression:

$$R = K.\ \Delta\theta.\ (1/U_1 - 1/U_2)$$

where K is the sensitivity constant determined by the calibration procedure; $\Delta\theta$, the temperature difference between the measuring head and the ambient air; and U_1 & U_2, the output voltages with and without fabric on the measuring head respectively. The thermal resistance value is expressed in mK.m^2/W.

2.3.2.5 Fabric Total Absorbency

Total absorbency, which measures the water holding capacity of the fabric, was determined by using 0.2% soap solution. A sample of the size 20 cm × 20 cm was dipped in the solution for 5 min, and then hung vertically to allow any extra water to drop down. It was then weighed and the percentage gain in weight of the fabric sample was taken as a measure of the total absorbency of the fabric. Fabrics were conditioned in a standard atmosphere for 24 h before all the tests were carried out.

3 Results and Discussion

3.1 Yarn Characteristics

Table 2 shows the diameter and hairiness of experimental yarns with respect to different process parameters. In general, MJS yarns are less hairy and have larger diameter than their ring-spun counterparts. Both diameter and hairiness increase as yarn linear density is increased. Increasing second jet pressure from 4 kg/cm^2 to 4.5 kg/cm^2 leads to a decrease in diameter and hairiness which later increase with further increase in second jet pressure to 5 kg/cm^2. Such a trend is the outcome of the increased wraps/cm at high second jet pressure. The increase in diameter and hairiness in the region above 5 kg/cm^2 pressure, on the other hand, might be attributed to the decreased incidence of wraps / cm. For both ring and MJS yarns, a striking improvement in hairiness can be achieved by diminishing the proportion of regenerated bamboo fibre in the mix.

3.2 Comfort Characteristics

3.2.1 Air Permeability

The influence of three experimental factors, viz. blend ratio, yarn linear density and spinning mode, on the comfort characteristics of woven bamboo-cotton fabrics was assessed for significance using ANOVA analysis (Table 3); the confidence level used was 99%. Figure 1 shows the comparative values of air

Table 3—ANOVA test results

Process variable	Fabric characteristics				
	Air permeability	Thermal resistance	Water vapour permeability	Wick-ability	Absorb-ency
Yarn linear density	s	s	s	ns	s
Fibre composition	s	s	s	s	s
Spinning mode	s	s	s	s	s
Second jet pressure	s	s	s	ns	ns

s-Significant at 99% confidence level, and ns-Non significant at 99% confidence level.

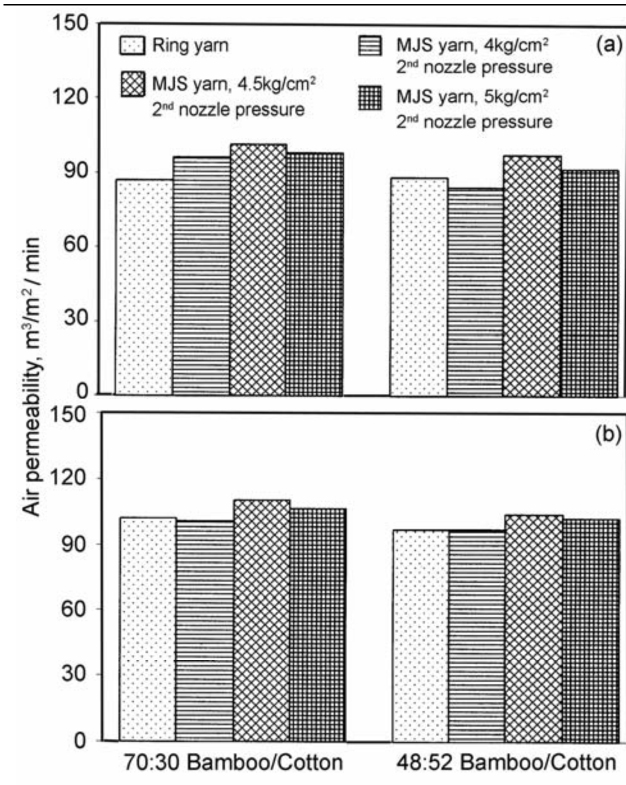

Fig. 1—Influence of process parameters on air permeability [(a) 19.6 tex; and (b) 14.7 tex]

permeability for the ring and MJS yarn fabrics measured as a function of fibre composition. The data clearly indicate that yarn structure does play an important role in influencing air permeability of bamboo-cotton fabrics. Invariably, the fabrics woven with MJS yarn exhibit considerably higher air permeability than the fabrics made with a ring-spun yarn. However, the air permeability values for 70:30 bamboo-cotton fabrics are substantially higher than that made from 48:52 bamboo-cotton mix. This can be explained in terms of the enhanced rate of air flow as a consequence of the reduced bulk of bamboo-majority yarns. In MJS yarn fabrics, the air permeability initially increases as the second jet pressure increases, and then decreases. This is particularly so because yarns produced with higher second jet pressure have the highest wraps/cm, the smaller diameter, and a lesser hairiness, which means that they offer less resistance to the flow of air. A higher second jet pressure beyond 4.5 kg/cm^2, on the other hand, results in fewer wraps/cm and irregular wrappings, which, in turn, leads to bulky and more hairy yarn[6]. Consequently, less space is available in fabrics for the passage of air. Increasing yarn linear density markedly reduces the air permeability regardless of blend ratio and yarn structure.

3.2.2 Thermal Resistance

Figure 2 depicts the mean values of thermal resistance for different fabrics. In general, MJS yarn fabrics exhibit appreciably higher thermal resistance than the corresponding ring-spun yarn fabrics. The fact that ring and jet spinning systems produce different yarn bulk, explains the observed trend. An increase in the cotton content in the fibre-mix improves the thermal resistance regardless of the yarn structure. The increased cotton content traps the air, making the structure more thermal resistant. Figure 2 also shows that 48:52 bamboo-cotton fabrics have significantly higher thermal insulation values than 70:30 bamboo-cotton fabrics, and that both types of fabrics display considerable increase in mean for the more dense structures. The results for variance analysis indicate that the second jet pressure has a significant influence on the thermal resistance of fabric. When the second jet pressure increases from 4 kg/cm^2 to 4.5 kg/cm^2, the subsequent result is a decrease in thermal resistance. The latter, however, enhances as the second jet pressure is further increased to 5 kg/cm^2. The more wraps/cm and small yarn bulk at 4.5 kg/cm^2 second jet pressure help to entrap more air, leading to higher thermal resistance.

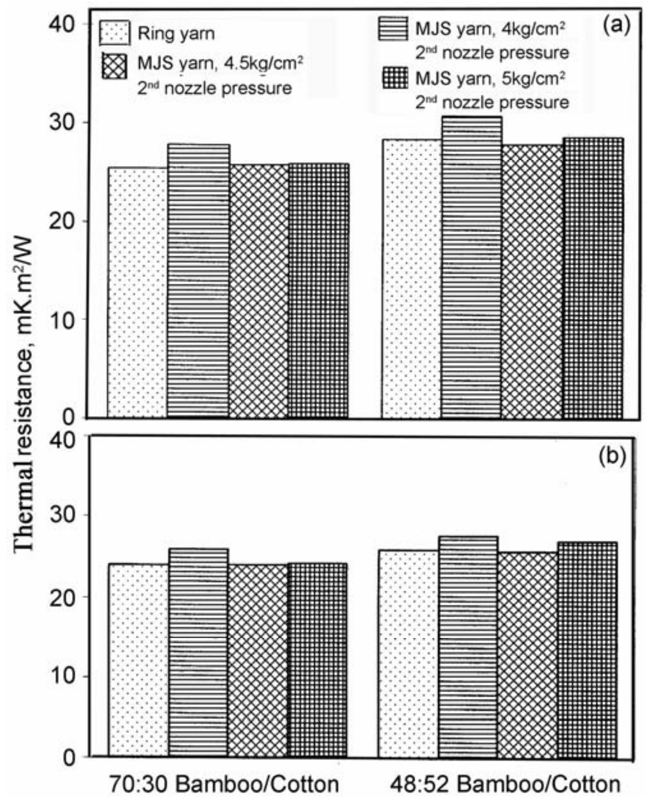

Fig. 2—Influence of process parameters on thermal resistance [(a) 19.6 tex; and (b) 14.7 tex]

3.2.3 Water Vapour Permeability

Figure 3 illustrates the values of water vapour permeability with respect to different process parameters. The water vapour permeability is highly dependent on the macro-porous structure of the constituent fibres. In Fig. 3, it is clearly seen that virtually all data for water vapour permeability lie in a wide range. The water vapour permeability is considerably higher for the 70:30 bamboo-cotton fabrics compared to that for the 48:52 bamboo-cotton fabrics. Higher moisture regain together with the macro channels present in bamboo fibre[7] represents no hindrance to moisture transfer in hydrophilic systems. Furthermore, water vapour permeability is significantly higher for MJS yarn fabrics and it increases with decreasing yarn linear density. The higher water vapour permeability of MJS yarn fabrics could be associated with the enhanced flow of water vapour through loose yarn structural matrix. For MJS yarn fabrics, the water vapour permeability increases noticeably when second jet pressure increases from 4 kg/cm^2 to 4.5 kg/cm^2. As the second jet pressure is further increased, water vapour permeability decreases irrespective of yarn linear density and fibre-mix. Such a behaviour of water vapour permeability arises due to

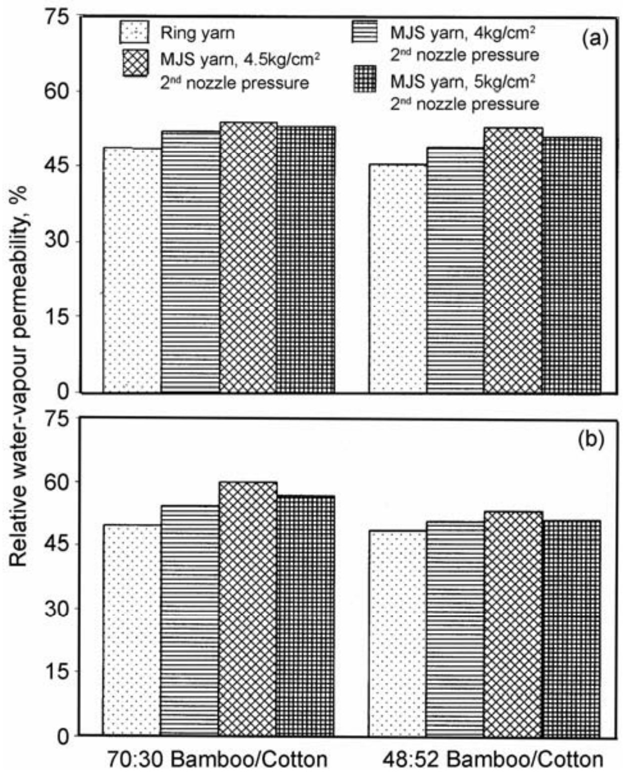

Fig. 3—Influence of process parameters on relative water-vapour permeability [(a) 19.6 tex; and (b) 14.7 tex]

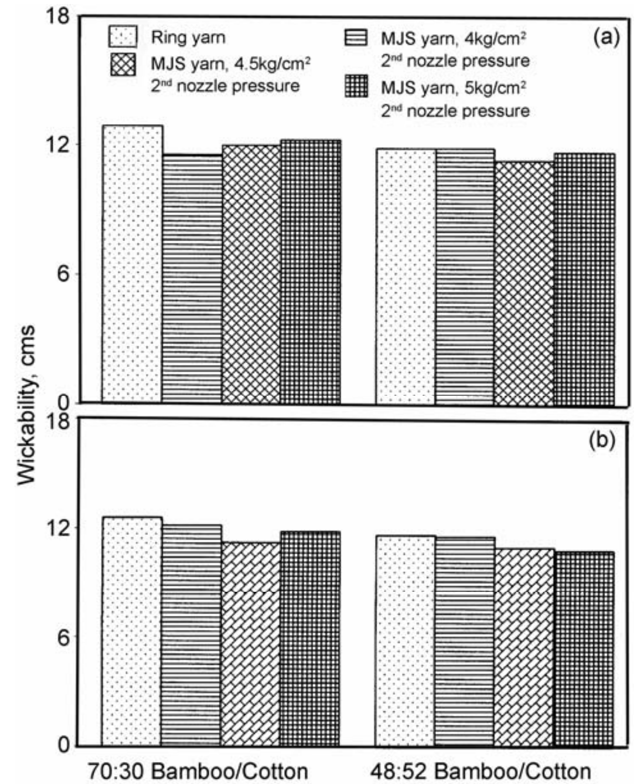

Fig. 4—Influence of process parameters on wickability [(a) 19.6 tex; and (b) 14.7 tex]

increase in yarn diameter caused by fewer wraps/cm, which reduces the exchange of water molecules in vapour form between two faces of the fabrics.

3.2.4 Wickability

Figure 4 shows the results of wickability test. Clearly the wickability values of the ring-spun yarn fabrics are higher than their equivalent MJS couples, and with increasing bamboo content, the wickability values increase for both types of fabrics. As already stated, the higher hydrophilicity together with macro channels present in the bamboo cellulose account for the enhanced wickability of bamboo-majority fabrics. Moreover, wickability values of fabrics made from yarns spun with different second jet pressures are quite close to each other and in most cases, the fabrics made of coarse yarns display slightly higher wickability than their fine yarn couples, as expected.

3.2.5 Total Absorbency

Figure 5 summarizes the absorption results for various bamboo-cotton fabrics. A comparison of the absorption indices shows that as a general trend for all materials, MJS yarn fabrics yield higher absorbency than the ring-spun yarn fabrics possibly due to less

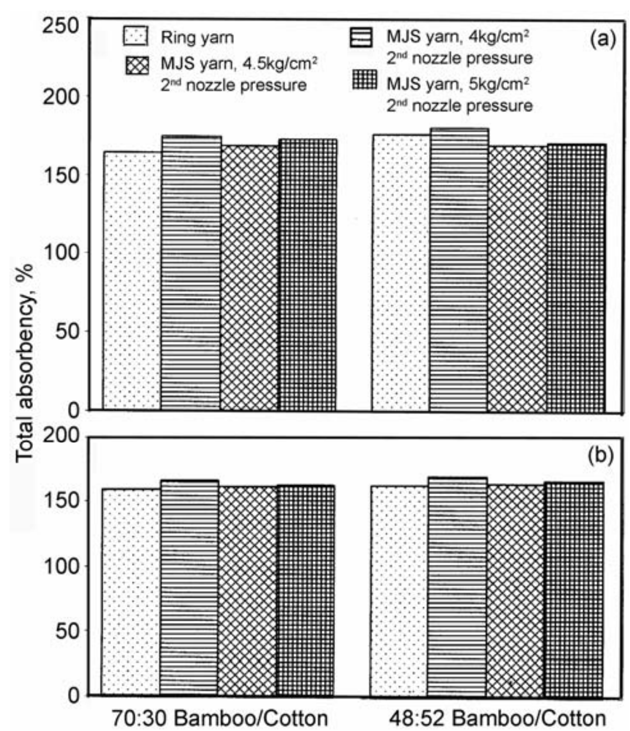

Fig. 5—Influence of process parameters on total absorbency [(a) 19.6 tex; and (b) 14.7 tex]

compact structure of MJS yarn, which favours the accessibility of the liquid. Although moisture regain of bamboo cellulose fibre is higher, the important point to note is that the total absorbency of the 48:52 bamboo-cotton fabrics is higher than that of 70:30 bamboo-cotton fabrics. This significant increase indicates that the wettability and penetrability of the material to liquid improve due to the macro channels present in the fibre which transfer water through fibre. The results also show that there are no marked differences between fabrics made from yarns spun with different second jet pressures, particularly in absorbency. Very remarkably, the absorbency of bamboo-cotton fabrics can be improved by using coarse yarns.

4 Conclusion

4.1 MJS yarn fabrics display considerably higher air and water vapour permeabilities, higher thermal insulation and lower wickability as compared to their ring-spun counterparts. With increasing second jet pressure, the air and water vapour permeabilities improve initially but decrease thereafter as the second jet pressure is further raised beyond a particular limit. On the other hand, the thermal resistance shows a sizeable decrease with increased second jet pressure up to 4.5 kg/cm^2. Further increase in second jet pressure up to 5 kg/cm^2 resistant, however, improves the thermal resistance. Moreover, the use of fine yarn structure contributes to the production of good quality fabrics with high air and water vapour permeabilities, less absorbency and poor thermal insulation.

4.2 Regenerated bamboo cellulose fibre offers no significant advantage in air-jet spinning with regard to fabric comfort. The fabrics produced with higher bamboo content, in general, are substantially more air and water permeable, less absorbent, have lower thermal resistance and yield higher wickability than the equivalent fabrics produced with cotton-majority mix.

4.3 The yarn structure and blend ratio are the important factors in determining fabric absorbency. The fabric woven with MJS yarn shows higher absorbency as compared to the ring-spun yarn fabric. The absorbency increases with the increase in the proportion of cotton fibre in the mix and decrease in yarn linear density.

4.4 Comfort analyses provide opportunities for engineering of textile substrates for various applications. Such studies are deemed critical to the understanding of the contribution of processing factors to the thermal comfort of woven bamboo-cotton fabrics, as well as broden applications of these materials for textiles.

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