

Thermal comfort properties of banana/bamboo blended fabrics

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This study focuses on the characteristics of thermal comfort woven fabrics made from a bamboo/banana blend. The effects of various fabric structures, such as satin, twill and plain weave fabrics made with various blended proportions of banana and bamboo fibres, have been investigated. The amount of banana fibres in the fabric increased its thermal conductivity, relative water vapour permeability and air permeability. The content of bamboo fibres, however, enhanced the fabric's thermal resistance characteristics. The satin weave increased the relative water vapour permeability, air permeability and thermal conductivity in accordance with the fabric structure, and the plain weave increased the thermal resistance characteristics of the fabric.

Keywords: Air Permeability, Blended yarn, Thermal Comfort, Thermal conductivity, Water vapour permeability, Woven fabric

1 Introduction

Physical, psychological, and thermal comfort are among the key factors influencing the comfort level of the clothing. Within these, the fabric's thermal comfort is crucial in maintaining the wearer's comfort level. The fabric's relative water vapour permeability, air permeability, thermal resistance and thermal conductivity have all been used to determine its level of thermal comfort. Recently, there has been significant research interest in examining the effects of thermal comfort properties on various textile materials.

Yang *et al.*¹ found that the double layer of fabric, which contains both hydrophilic and hydrophobic materials, improved the fabric's thermal comfort characteristics. Su *et al.*² concentrated their research on the thermal comfort characteristics of cotton fabrics and discovered that adding cotton fibres increased the fabric's capacity to absorb water while simultaneously slowing down its drying rate. Gericke *et al.*³ investigated the effect of fabric physical characteristics like thickness, porosity, and fabric structures on thermal comfort properties. Mao and Rusell⁴ examined the thermal comfort behaviour of the fabrics based on the fibre and fabric thickness.

Stankovic *et al.*⁵ studied the thermal comfort of fabrics made from natural and regenerated cellulosic

fibres. Dal *et al.*⁶ highlighted that the fabric's cover factor has a major impact on how comfortable it is to wear. Sampath *et al.*⁷ established an inverse relationship between a fabric's areal density and thermal resistance. According to Mandal and Song⁸, the thickness of the fabric—serving as an insulating medium for the movement of air outside—significantly impacts how much heat is transferred through it. Chidambaram *et al.*⁹ noted that the physical characteristics of fibres and fabrics significantly impact wear comfort. According to Prakash and Ramakrishnan¹⁰, fabrics made with finer-diameter polyester fibres exhibit higher water vapour permeability. Prakash¹¹ studied that bamboo fibre has excellent antibacterial, quick-drying, and hygroscopic properties. Lipp-Symonowicz *et al.*¹² compared viscose and bamboo fibres and found that their thermal comfort properties were similar. Wardiningsih and Troynikov¹³ studied the moisture management properties of recycled bamboo fibre knitted fabrics using different fabric cover factors, finding that as fabric density increased, the wetting radius decreased, and overall moisture management ability declined.

Majumdar *et al.*¹⁴ analyzed the characteristics of knitted fabrics manufactured from natural fibres like wool, cotton, and regenerated fibres of bamboo. They observed that the physical structure of the fabric has a good impact on the fabric's water vapour permeability

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and air permeability. Mikucioniene and Arbataitis¹⁵ reported that knitted fabrics made from regenerated bamboo fibres exhibit thermal comfort properties comparable to those of cotton fabrics. Structural parameters like loop length and spacing of the loops also affect thermal comfort, with an increase in loop length leading to higher thermal conductivity.

Researchers have explored the development of eco-friendly fabrics, with banana fibre emerging as a sustainable alternative. Vardhini *et al.*¹⁶ identified various methods for extracting banana fibres, like mechanical, manual, biological and chemical methods.

Banana and bamboo fibres have several characteristics that make them highly suitable for textile applications, such as being lightweight, moisture-wicking, and offering excellent thermal insulation. Studies have shown that blending these fibres enhances the thermal comfort properties of fabrics. Specifically, banana/bamboo blended fabrics exhibited better thermal insulation than pure banana or bamboo fabrics, and lower thermal conductivity, indicating improved heat retention. Researchers attributed these enhanced properties to the high porosity and moisture-wicking capabilities of the blended fabrics¹⁷. Hence, this research investigates the thermal comfort characteristics of the bamboo/banana blended fabrics.

2 Materials and Methods

Commercially available bamboo and banana fibres were procured from the market. The characteristics of these fibres are mentioned in Table 1.

2.1 Yarn Manufacturing

Banana and bamboo slivers were blended in three different ratios: 100:0, 50:50 and 0:100. The blending process was carried out in the Lakshmi manufacturing line to develop 60s Ne yarn. The yarn unevenness was assessed using an unevenness tester at a speed of 100 m/min. The yarn tenacity was determined using Zwick universal testing equipment, while yarn hairiness was determined using a Zweigle hairiness

instrument. All experiments were conducted under standard atmospheric conditions (65 ± 2 % relative humidity) and temperature ($20 \text{ }^\circ\text{C} \pm 2 \text{ }^\circ\text{C}$).

2.2 Fabric Manufacturing

Woven fabrics were produced using three different weaves, namely plain, 2/2 twill and 7/1 satin. An SDL fabric digital thickness tester was used to determine the fabric thickness following ISO 5084 standard. Fabric density was determined according to the ASTM D3775 standard. The fabric areal density was determined by the standard of ASTM D3776.

2.3 Thermal Comfort Analysis

The thermal comfort properties of the fabric were evaluated through multiple parameters. The air permeability was measured using the TEXTTEST FX3300 instrument, following the ASTM D737-2004 standard. The air permeability was calculated based on the airflow rate between the inner and outer fabric surfaces. The water vapour permeability was determined by the PermiTest equipment with the standard of ISO 11092, which operates based on the heat flux principle. Heat loss was recorded through the evaporation of water from the fabric surface. The Alambeta instrument was used to estimate the thermal resistance and thermal conductivity of fabrics according to the ISO 11092 standard. This device comprised a cold and hot plate, between which fabric samples were placed. Thermal conductivity and thermal resistance were calculated based on the heat flow from the hot side to the cold side upon contact with the fabric sample.

2.4 Statistical Analysis

A two-way analysis of variance (ANOVA) was performed to evaluate the significance of the differences in thermal comfort properties across various fabric samples, considering both the banana/bamboo blending ratios and weave structures. For statistical significance, a threshold P-value of 0.05 was set, indicating that differences with a P-value at or below this level were considered significant.

3 Results and Discussion

3.1 Physical Characteristics of Blended Yarns

The physical characteristics of bamboo/banana blended yarns are shown in Table 2. It is noted that the unevenness of the fabric is more with the bamboo fibres and decreases with the banana fibres. A similar trend is observed for thick and thin places in the yarn.

Table 1 — Characteristics of banana and bamboo fibres

Characteristic	Banana	CV, %	Bamboo	CV, %
Fibre length, mm	42	1.12	38	1.73
Fibre denier	1.53	2.30	1.41	2.14
Tenacity, g/d	2.99	2.13	3.7	1.54
Specific density, g/cm ³	1.37	1.23	1.33	2.31
Elongation, %	19	1.14	22	0.92
Moisture regain, %	13.00	2.23	11.11	2.24

The yarn produced from bamboo fibres exhibits higher irregularities due to the presence of more uncontrolled fibres in the drafting zone, making it difficult to integrate bamboo fibres effectively during spinning¹⁸. This results in increased yarn irregularities. Additionally, yarn tenacity decreases with the inclusion of bamboo fibres due to their weaker cohesion and lower tenacity¹⁹.

3.2 Geometrical Characteristics of Blended Fabrics

Table 3 shows the geometric properties of the bamboo/banana blend fabrics. The areal density of the fabric increases with increasing bamboo fibre content due to the bulkiness and irregular nature of bamboo fibres. In addition, twill weave fabrics exhibit a higher areal density than plain and satin weave fabrics. As the bamboo fibre content increases, the porosity also increases, which is attributed to the increased space between the warp and weft yarns caused by the uncontrolled behaviour of bamboo fibres in the drafting zone of spinning.

3.3 Air Permeability

The comfort behaviour of the wearer majorly depends on the fabrics’ air permeability. The air permeability of banana/bamboo blended fabrics of plain, twill and satin weave is shown in Fig. 1. It is noted that the fabric air permeability is decreased with the addition of the bamboo fibre, and this is because

of the higher unevenness and bulkiness structure of the bamboo yarn which will hinder the more air passage through the fabric. Militky *et al.*²⁰ studied the fact that fabric air permeability is also influenced by fabric porosity. Bulky and uneven yarns (e.g., from bamboo fibres) can fill up fabric pores, reducing air permeability despite an inherently porous structure. Among the weave structures, satin weave exhibits the highest air permeability due to its increased porosity, while plain weave has the lowest.

3.4 Thermal Conductivity

The thermal conductivity of plain, twill, and satin bamboo/banana blended fabrics demonstrates that the fabrics made from banana fibres have high thermal conductivity (Fig. 2). This is attributed to higher thermal conductivity between yarns, resulting in higher porosity. Satin weave fabrics exhibit the highest thermal conductivity owing to their higher porosity.

3.5 Thermal Resistance

The thermal resistance characteristics of blended banana/bamboo fabrics in different weave structures

Table 2 — Physical characteristics of banana/bamboo blended yarns

Characteristics	100:0	50:50	0:100
Count, Ne	60.2	59.8	60.4
U, %	9.1	10.15	11.2
Thin, -50%/Km	3.45	5.23	7.2
Thick, +50%/Km	34	42	63
Neps, +200%/Km	92	110	131
Hairiness	2.45	2.92	3.9
Tenacity, g/den	301.12	295.13	290.09

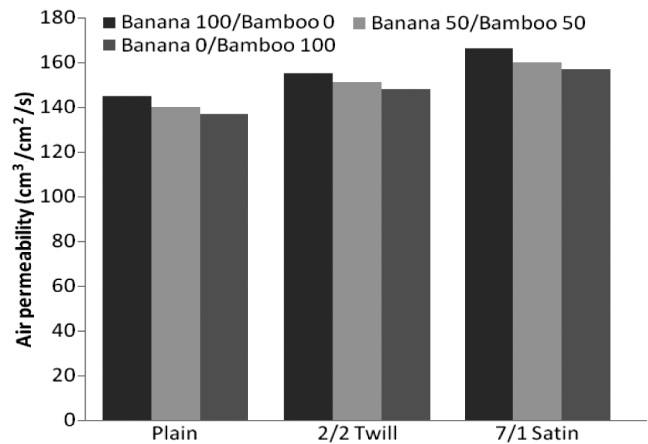


Fig. 1 — Air permeability of banana/bamboo blended fabrics

Table 3 — Geometrical characteristics of banana/bamboo blended fabrics

Blend ratio	Weave	Areal density, g/m ²	End per cm	Picks per cm	Thickness, cm	Porosity, %
100:0	Plain	94	74	94	0.038	77.23
	Twill	97	79	97	0.045	83.45
	Satin	87	85	87	0.042	86.48
50:50	Plain	95	75	95	0.037	79.45
	Twill	98	79	99	0.043	85.18
	Satin	89	84	89	0.041	88.45
0:100	Plain	96	74	96	0.035	81.07
	Twill	99	78	97	0.042	86.43
	Satin	90	84	81	0.041	89.87

are shown in Fig. 3. It is observed that fabrics containing bamboo fibres possess higher thermal resistance due to their bulkiness, which acts as thermal insulation. Conversely, fabrics composed of banana fibres exhibit lower thermal resistance due to their higher porosity. Satin weave fabrics demonstrate the highest thermal resistance, whereas plain weave fabrics show the lowest.

3.6 Relative Water Vapour Permeability

Figure 4 presents the relative water vapour permeability of banana/bamboo blended fabrics in

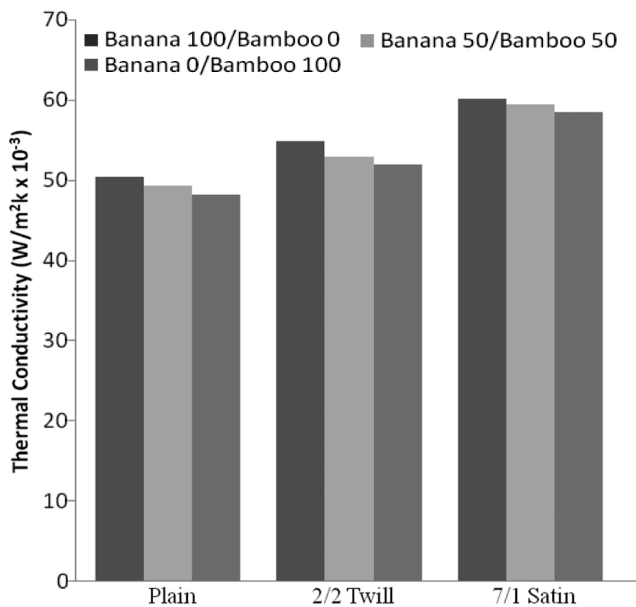


Fig. 2 — Thermal conductivity of banana/bamboo blended fabrics

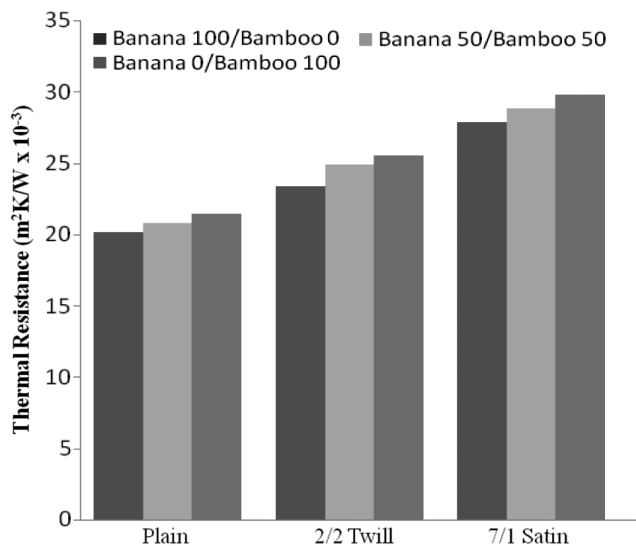


Fig. 3 — Thermal resistance of banana/bamboo blended fabrics

satin, twill, and plain weaves. Fabrics composed of banana fibres display higher water vapour permeability, which decreases with the addition of bamboo fibres. This is because of the higher porosity of banana fibres and more space between the warp and weft yarns. This wide gap in the banana fabrics helps to transport water vapours from one fabric surface to another. Satin weave fabrics exhibit the highest relative water vapour permeability, while plain weave fabrics have the lowest due to their porosity levels.

3.7 Statistical Analysis

To evaluate the statistical significance of the effects of blend proportion and weave structure on the thermal comfort properties, a two-way analysis of variance (ANOVA) was performed (Table 4). The results indicate that both factors significantly influence thermal comfort properties. The p-value associated with the thermal comfort properties of the fabric is less than 0.05. This implies a significant difference in the influence of blend ratio and fabric structure on the thermal comfort properties of the fabric at a 95% confidence level. Consequently, it can be concluded that the blend ratio and fabric structure significantly impact various key properties of the fabric, including air permeability, relative water vapour permeability, thermal resistance, and thermal conductivity.

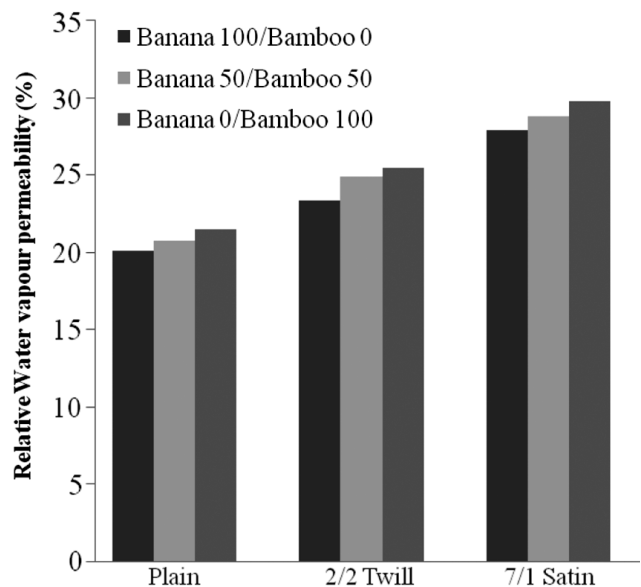


Fig. 4 — Relative water vapour permeability of banana/bamboo blended fabrics

Table 4 — Two-way ANOVA of blend proportion and fabric structure on thermal comfort properties

Source	SS	df	MS	F	P-value	F-crit	Sig.
Blend ratio	98	2	49	147	0.00018	6.94	s
Structure	620.67	2	310.34	931	4.6 X 10 ⁻⁶	6.94	
Error	1.33	4	0.33				
Total	720	8					
Blend ratio	4.80	2	2.40	37.59	0.002552	6.94	
Structure	97.21	2	48.60	761.05	6.87 X 10 ⁻⁶	6.94	s
Error	0.25	4	0.06				
Total	102.27	8					
Blend ratio	8.04	2	4.02	26.99	0.0047	6.94	s
Structure	153.17	2	76.59	514.19	1.5 X 10 ⁻⁵	6.94	
Error	0.60	4	0.15				
Total	161.81	8					
Blend ratio	13.84	2	6.92	104.79	0.000351	6.94	s
Structure	116.03	2	58.01	878.20	51.6 X 10 ⁻⁶	6.94	
Error	0.26	4	0.07				
Total	130.15	8					

“s” means statistically significant at 95% confidence level

Conclusion

This study investigates the impact of bamboo/banana fibre blend ratios and weave structures on the physical and thermal comfort properties of fabrics. The results indicate that fabric air permeability and relative water vapour permeability are higher in fabrics made from banana fibres and those with a satin weave due to their increased porosity. Conversely, thermal resistance is greater in fabrics containing a higher proportion of bamboo fibres and in plain weave structures, as bamboo fibres exhibit bulkier characteristics that enhance thermal insulation. Thermal conductivity is higher in banana fibre fabrics due to better heat transfer through the yarns. The statistical analysis confirms that both blend ratio and fabric structure significantly influence these properties.

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