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Evaluation of Underwear Bamboo/Cotton Knitted Fabrics Comfortability

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Abstract

The comfort properties of the underwearare one of the most important aspects affects human satisfaction while wearing clothes. Since most of the researches which study the comfort underwear properties concerns about either moisture management properties or thermal properties. In this study both thermal properties and moisture management properties were studied. The relation between constructional parameters and some physical properties on the following comfort properties (air permeability, water vapour permeability, thermal resistance, thermal conductivity, and vertical wicking time in both wales and courses directions) were studied for three single jersey knitted fabrics produced from different yarn materials 100% cotton, 70% bamboo/30% cotton, 100% bamboo on two machine gauges 24inches, 28 inches in attempt to determine the most suitable fabric for underwear. The same yarn count Ne 30 were used for all materials. Each fabric is knitted with three different loop lengths Tight, medium, and loose structure. It was found that loop length is a significant factor that affects air permeability, and water vapour permeability. Vertical wicking time in both wales and courses direction positively. While it has negative effect on thermal resistance. Fabrics with the highest loop lengths (loosest fabrics) have the highest air and water vapour permeability, and the highest vertical wicking rate in both wales and courses direction, while they have the lowest thermal resistance. The type of fabric material has a significant effect on air permeability. Water vapour permeability, thermal conductivity, vertical wicking rate in both wales and courses directions. 100% Bamboo fabrics have the highest air permeability, water vapour permeability, thermal conductivity, and vertical wicking rate in both wale and course directions, then comes 70% bamboo/ 30% cotton then comes 100% cotton fabrics. Thicker fabrics have lower air permeability. Machine gauge interacts with loop length and affects vertical wicking rate in both wale and course directions. Also, the machine gauge affects water vapour permeability and thermal resistance. Fabrics produced on a machine gauge of 28 inches (tighter fabric) have lower water vapour permeability and higher thermal resistance than fabrics produced on a machine gauge of 24 inches. It was found that bamboo and bamboo/cotton knitted fabrics are more suitable for manufacturing underwear than cotton knitted fabrics.

Keywords: Knitted fabric, bamboo, comfort properties, air permeability, thermal conductivity, vertical wicking.

1. Introduction

Textile and apparel manufacturers are exploring natural renewable fibres which have unique performances to add value to their products and to catch the attention of the consumers. These led to research concerns about developing fibre derived from unconventional ‘agro-resources’ such as bamboo[1].

Bamboo textiles are comfortable and durable[2, 3, 4], and they also feature high-performance qualities like antimicrobials that lower the chance of allergies [3]. Additionally, bamboo apparel is UV-resistant, breathable, and effectively absorbs perspiration. Additionally, bamboo can eliminate bacteria that cause odours on human skin, improving the smell of the wearer's clothes. Furthermore, because of its insulating qualities, bamboo cloth will keep its wearer warmer in the winter and colder in the summer [3].

Heat and moisture comfort of bamboo, cotton bamboo, modal, and cotton knitted fabrics used in the market for underwear fabrics were measured and analysed to evaluate the heat and moisture comfort of these fabrics. The evaluated fabrics were ranked in terms of heat and moisture comfort as modal, bamboo, cotton/bamboo and cotton, in terms of heat and moisture comfort [5].

The comfort properties of knitted fabrics (single jersey) made from different bamboo blends were studied. Increasing in the percentage of bamboo fibre in the fabric causes a reduction in fabric thickness and weight for all linear densities of fabrics. Air and water vapour permeability increased with the increase in bamboo fibre content while thermal conductivity decreased (6–11). Also, thermal resistance shows a decreasing trend with increasing bamboo content[6–10].

Comfort and mechanical properties of different blends of polyester/bamboo and polyester/cotton knitted fabrics single jersey knitting machine were studied. It was found that increasing cotton and bamboo ratios or fibre content increased air permeability and moisture management capability, while Increasing bamboo ratio decreased thermal resistance because of lower thickness this may be attributed to a low diameter of bamboo fibre as compared to polyester fibre, which causes compression of layers reducing fabric thickness [12].

The effect of fabric composition (bamboo, cotton, and microfiber polyester) blends of different materials obtained by different arrangements of the machine yarn feeders of single jersey knitting machine on thermal comfort properties were studied. The fabric composition has a significant effect on thermal conductivity, Q max, fabric thickness, and fabric weight. The presence of bamboo fibre in the fabric increased thermal conductivity, and decreased fabric thickness [13].

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The Influence of fabric parameters on the wicking behaviour of polyester lycra knitted fabric was studied. As the loop length increased there was an improvement in vertical wick ability regardless knitted structure [14].

100% cotton, 100% bamboo fabric, and different blends of bamboo/cotton, and polyester/ cotton with different blend proportions were used to produce single jersey knitted fabric samples. Knitted fabrics were used in an attempt to predict suitable combination material for wound dressing. 100% bamboo has the highest air permeability value.In blended fabric air permeability tends to be decreased as the thickness increases. Bamboo gives the highest air permeability because of the micro spaces in the fabric structure. For bamboo/cotton blended knitted fabric, increasing bamboo content increased the thermal resistance of the blend. Air permeability, thermal resistance and moisture management are high for bamboo/cotton blended knitted fabric. Also, it has high thermal resistance, and the thermal conductivity is less [15].

Rib 1×1 fabric was knitted using bamboo and cotton yarns with different rations 100% cotton fabric, 100% bamboo fabric, 83/17 bamboo/cotton, 17/83 cotton/bamboo. The OMMC, air and water vapour permeability were measured. It was found that all fabrics gave good OMMC and fabric parameters did not affect the moisture transport behaviour of fabric. While the fabric with 83/17 bamboo cotton has the highest air and water vapour permeability [16].

Thermal comfort properties of fabrics knitted from bamboo/cotton blended yarns with plain knit, pique knit and double knit 70% bamboo/30% cotton, 100% cotton, 100% modal, 50/50 modal cotton with Ne 30/1 were studied. There was a significant effect of raw material on thermal resistance.

The lowest water vapour and thermal resistance were obtained for 70% (bamboo) / 30% (cotton) [17].

Thermal properties of knitted fabrics (plain, 1 x 1 rib and interlock) made from cotton and regenerated bamboo cellulosic fibres were studied.

100% B, 100% cotton, 50% bamboo, 50% cotton, with 30, 24, and 20 tex were used to manufacture the knitted fabrics. Thermal conductivity reduced when the bamboo percentage increased. For the same fibre blend proportion thermal conductivity was lower for finer yarns. Air and water vapour permeability increased as the percentage of bamboo increased.

Plain knitted fabrics show the minimum thermal conductivity and resistance followed by rib and interlock. Water vapour permeability was the highest for plain and the lowest for interlock [18].

Thermal comfort properties of single jersey knitted fabric knitted from bamboo, tencel, and their blend from 30 Ne with loose, medium and tight structures were studied. Thermal conductivity and resistance, water vapour and air permeability were measured. Thickness and weight decreased with higher loop length. Air permeability and water vapour permeability increased when Tencel % increased. Also, air and water vapour permeability increased with looser fabric. As the proportion of tencelfiber content increased the thermal conductivity decreased and vice versa. For thermal resistance with an increase in tencel percentage, the thermal resistance increased. Thermal conductivity was higher for tighter fabrics for the same yarn composition and vice versa. The tighter structure has less thermal resistance [19].

The wicking and drying behaviours of knitted fabrics produced with different polyamide yarns were studied. Fibre type has a significant effect on the transverse wicking ratios of dyed samples. Transverse wicking rates of merely skin life and nylon garments tended to increase while tactel decreased by washing. Transverse wicking of loose samples had the highest values for all conditions irrespective of fibre type [20].

Effect of fibre content on comfort properties of cotton/spandex, Rayon/spandex, and polyester/spandex single Jersey knitted fabric with 5% spandex blended with each material.

Polyester spandex had the lowest thickness then came rayon spandex then cotton spandex. Polyester has the highest air permeability than rayon, then cotton. The study showed that fibre content can influence the performance attributes of fabric. The polyester/spandex blend had the highest air permeability and lowest stretch recovery rate. Both rayon/spandex and polyester/spandex did not show any horizontal wicking at all and cotton/spandex showed a weak horizontal wicking rate. Thickness affected air permeability and recovery but did not affect stretch and wicking [21].

Thermal properties of greige and dyed fabrics made of cellulosic fabrics (100% cotton combed and carded, 100% modal, 100% Tencel, curpo, Umorfil (100% cellulosic and collagen peptide added fabrics) with 30 Ne were studied. It was found that thermal conductivity, thermal absorptivity, and thermal resistance were significantly influenced by fibre type. Knitted fabrics made out of Umorfil material showed the lowest thermal conductivity while fabrics made from cotton combed yarns showed the highest thermal conductivity. Thermal resistance for dyed fabrics was the highest for 100% carded cotton fabric while the lowest was obtained for 100% Tencel fabric. Yarn type was found to be a significant factor that affects air permeability. Cellulosic fabrics show higher air permeability than combed and carded cotton fabrics [22].

Bamboo yarns with three linear densities 20, 25, and 30 Ne were used to construct single jersey knitted fabric with three loop lengths of 2.7 mm, 2.9 mm, and 3.1 mm. The effect of loop length as well as linear density on comfort properties was studied; it was found that thermal conductivity increased with decreasing the loop length. As the linear density increased the thermal conductivity increased. Air permeability increased with the increase in both linear density and loop length. No significant difference was found for relative water vapour permeability for the bamboo fabrics as it depends highly on the macro-porous structure of the fibres [23].

Thermal conductivity and water vapour resistance of different knitted single jersey fabrics made from 100 % wool, 100% cotton, 100% polyester, and wool blend collected from the market were studied. Thermal conductivity was affected by fibre type, fabric thickness, and fabric structure while water vapour resistance was affected by fabric optical porosity and fabric thickness [24].

This work aims to analyse comfort properties of knitted fabrics used to manufacture healthy under wears to determine the most suitable fabric for underwear. The relation between knitted fabric constructional parameters and physical properties on the measured comfort properties for these fabrics was studied.

2. Materials and methods

2.1. Material and fabric manufacturing

Three yarn types were obtained from a spinning mill with the same yarn count Ne30/1. 100% combed cotton yarn as well as 70% bamboo / 30% Cotton, and 100% Bamboo yarns. Each yarn was used to produce single jersey knitted fabric on two knitting machines.17 inches diameter single jersey circular knitting machine gauge 24, and 21 inches diameter Single jersey circular knitting machine gauge 28. The fabrics were produced from three different yarn types.

The two knitting machines with the two gauges were adjusted to produce fabrics from each yarn type with three different loop lengths (2.7, 2.9, 3.1 mm) which gives three different tightness factors for each kind of fabric. Finishing of fabric samples. The fabrics were finished according to the factory procedures. The produced fabrics were scoured to remove the noncellulosic materials according to their type. 100% Cotton and 70% bamboo l30 % cotton fabrics were scoured at 95° C for 30 minutes, while 70% bamboo / 30% Cotton was scoured at 70ºC for 20 minutes followed by rinsing.

Then the scoured fabrics were finished using wetting detergent, fatty acid, silicon hydrophilic, and polyethylene by pad-dry method followed by compactor and left for 24 hours for relaxation. 100% Bamboo fabrics were not scoured according to factory procedures. They were finished only and left for 24 hours for relaxation. Finally, finished fabric samples were taken to measure their physical and comfort properties.

2.2. Methodology

One-way analysis of variance ANOVA with a confidence level of 95% was applied for each measured property to find the significant differences between the three fabric samples (bamboo, bamboo/cotton, and cotton) for each measured property. A step-wise regression was done to determine the effect of fabric physical and constructional parameters, type of material, and machine gauge on each comfort property under study.

2.3. Fabric testing

After keeping the finished samples for 72 h in standard conditions (relative humidity = 65 ± 2% and temperature = 20 ±2°C), the fabric properties were measured. According to [25].

2.3.1. Fabric weight per unit area

Standard procedures for measuring GSM for produced fabric samples according to ASTM-D3776-1996 followed by using digital measuring balance [26].

2.3.2. Fabric thickness

Fabricssamples thickness was measured according to standard ASTM-D1777[27].

2.3.3. Measuring stitch density

Stitch density and length are obtained by counting the number of courses and the number of wales in one inch. According to (ASTM D-3887, 1996) [28].

2.3.5. Air permeability

Air permeability of the samples were measured according to ASTM standard D -737- 2018[29].

2.3.6. Water vapour permeability

Water vapour permeability of fabric samples was measured on Permetest at National Institute For Standards according to the standard ISO 11092 [30].

2.3.7. Thermal resistance

Thermal resistances of fabric samples were measured on Permetest according to the standard ISO 11092. The thermal resistance was measured in mk.m^2/w[30].

2.3.8. Thermal conductivity

Thermal conductivity was determined by KES-F7 Thermo Lab.

2.3.9. Vertical Wicking

Vertical Wicking of fabric samples was measured according to AATCC Test Method 197-2013. Measuring time at a given distance method was used [31].

3. Results and discussion

Table 1 displays the loop length, weight, thickness, air permeability, water vapour permeability, and thermal resistance of cotton, bamboo/cotton, and bamboo fabrics produced on knitting machine gauge 24, while Table 2 displays the same properties for gauge 28.

Table 1: Fabric specifications of fabrics produced on gauge 24

Material	**Loop length (mm)**	**Weight (g/m^{2})**	**Stitch density**	**Thickness (mm)**	**Air permeability (cm^2/cm^3/s)**	**Water vapour Permeability (%)**	**Thermal resistance (mk.m^2/w)**	**Thermal conductivity (W/cm. °C)**	**Vertical wicking time in wales direction (second)**	**Vertical wicking time in courses direction (second)**
c	2.7	131.5	1872	0.39	94	64.08	10.04	0.0028236	300.7	257.3
	2.9	122.7	1720	0.39	102.8	63.3	8.3	0.0026832	494.3	294
	3.1	115	1482	0.368	157.8	64.88	7.3	0.00239936	540	495.3
cb	2.7	145	1920	0.41	120.2	67.9	11.28	0.0029356	43.3	111
	2.9	127	1665	0.41	205	66.02	9.36	0.0031324	78	131
	3.1	115.6	1482	0.382	221.2	68	7.76	0.00279624	114	95.3
b	2.7	135	1872	0.37	216	67.22	10.8	0.00296	43.3	54.3
	2.9	121	1672	0.37	284.4	69.4	9.4	0.0027528	59.3	39
	3.1	112.6	1365	0.351	302	66.3	7.94	0.00270972	50.7	44

C: cotton fabric, cb: cotton/ bamboo fabric, b: bamboo fabric

Table 2: Fabric specifications of fabrics produced on gauge 28

Material	**Loop length (mm)**	**Weight (g/m^{2})**	**Stitch density**	**Thickness (mm)**	**Air permeability (cm^2/cm^3/s)**	**Water vapour Permeability (%)**	**Thermal resistance (mk.m^2/w)**	**Thermal conductivity (W/cm. °C)**	**Vertical wicking time in wales direction (second)**	**Vertical wicking time in courses direction (second)**
c	2.7	142.8	2009	0.408	65.2	56.9	11.66	0.00292128	408	432.5
	2.9	123.6	1677	0.406	95	61.32	12.7	0.00303688	762.8	845
	3.1	115.8	1520	0.397	143	62.86	13.76	0.00290604	1200	1196.7
cb	2.7	142.2	1960	0.398	129	59.88	12.7	0.002786	223.7	81.7
	2.9	120.6	1665	0.383	184	63.32	10.5	0.00289548	87	72
	3.1	110	1520	0.38	188	64.86	9.52	0.002964	97	118.3
b	2.7	133.8	1880	0.361	200	62.86	12.12	0.00271472	46.3	54
	2.9	114	1554	0.361	261	66.74	10.6	0.00284468	70.7	60
	3.1	107.8	1443	0.3483	283	65.32	10.64	0.00295104	51.7	127.3

C: cotton fabric, cb: cotton/ bamboo fabric, b: bamboo fabric

The significant differences between the three fabric samples (bamboo, bamboo/cotton, and cotton) for each measured property were found using One-way analysis of variance ANOVA with a confidence level of 95% applied for each measured property. The effect of fabric physical and constructional parameters, type of material, machine gauge on each comfort property under study was determined using stepwise regression analysis.

3.1 Comfort properties

Most of comfort properties which are air permeability, water vapour permeability, thermal resistance, thermal conductivity, and vertical wicking in both wales and courses direction were measured for fabrics under study. Where c symbolizes cotton fabric, cb symbolizes bamboo/cotton fabric, and b symbolizes bamboo fabric.

3.1.1 Air permeability

Applying a one-way ANOVA test for three fabric samples (bamboo, bamboo/cotton, and cotton) for the same stitch length. It was found that there was a significant difference in air permeability between bamboo fabric, bamboo cotton fabric, and cotton fabric for both machine gauges 24 and 28. The p- values are shown in Table 3

Table 3: p- values for differences in air permeability between the three fabrics

Machine gauge (inches)	**Loop length (mm)**	**P- value**
Gauge 24	2.7	8.13E-14
	2.9	2.7E-12
	3.1	3.32E-11
Guage 28	2.7	8.2E-13
	2.9	3.08E-10
	3.1	3.73E-11

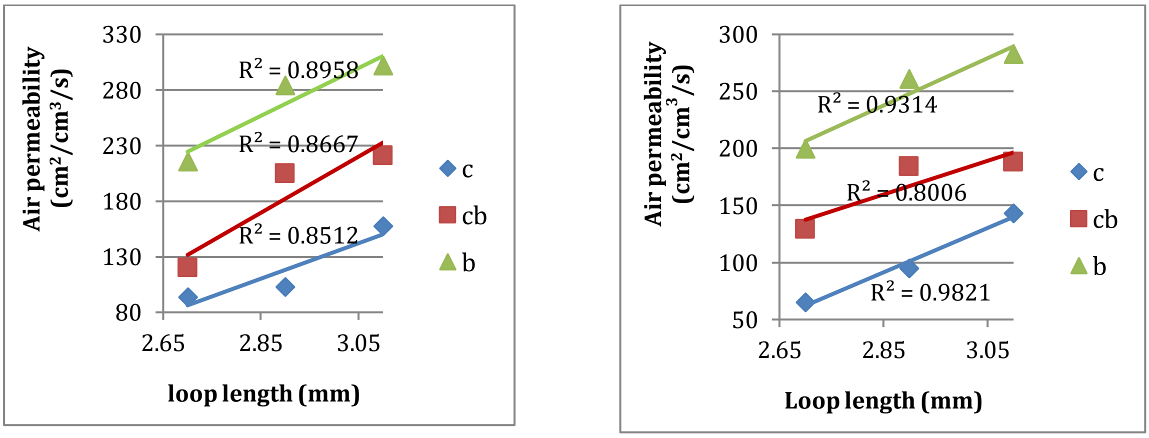
A stepwise multiple regression analysis was done to predict air permeability from fabric constructional and physical parameters.

$$Air\ permeability = 409.8 + 30.6 * looplength - 927.4 * thickness + 113.3 * material$$

R^2=0.92 Equation 1

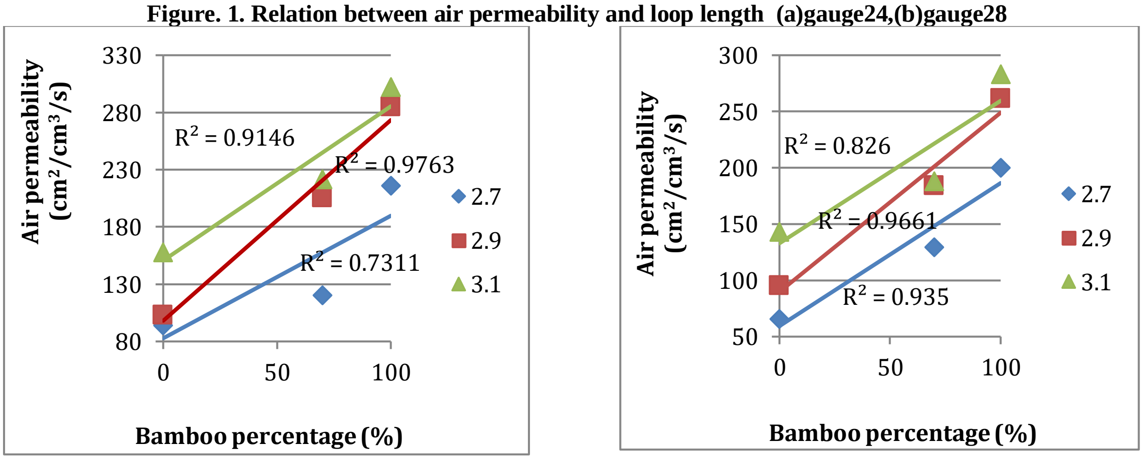
From equation 1 it could be predicted that loop length has a positive effect on fabric air permeability which means that the looser fabric with higher stitch length has higher air permeability while fabric thickness has negative effect on air permeability which means that thicker fabric has less air permeability (agrees with 33). Also, the effect of fabric material appears in the equation. Cotton fabric with zero bamboo percentage has the lowest air permeability then comes the bamboo cotton fabric with 70% bamboo and 30% cotton and then comes the 100% bamboo fabric which has the highest air permeability agrees with (6-11,32). This may refer to lower hairiness of bamboo fibres than cotton fibres.

Figures 1(a and b) show the relation between air permeability and loop length for both machine gauges24 inches, and 28 inches, while figures 2(a and b)show the relation between air permeability and bamboo percentage for both machine gauges 24 inches, and 28 inches. The figures emphasize the results of Equation 1.



(a) **(b)**

Figure. 1. Relation between air permeability and loop length (a)gauge24,(b)gauge28



(a) **(b)**

Figure. 2. Relation between air permeability and bamboo percentage (a) gauge24, (b) gauge28

3.1.2 Water vapour permeability

Applying a one-way ANOVA test for three fabrics samples (bamboo, bamboo/cotton, and cotton) for the same stitch length. It was found that there was a significant difference in water vapour permeability between bamboo fabric, bamboo/ cotton fabric, and cotton fabric for both machines gauges 24 inches and 28 inches. The p- values are shown in Table 4

Table 4:p-values for differences in water vapour permeability between the three fabrics

Machine gauge (inches)	Loop length (mm)	P- value
Gauge 24	2.7	0.000146
	2.9	5.43E-07
	3.1	1.71E-19
Guage 28	2.7	7.42E-05
	2.9	0.000751
	3.1	0.000368

A stepwise multiple regression analysis was done to predict water vapour permeability from fabric constructional and physical parameters.

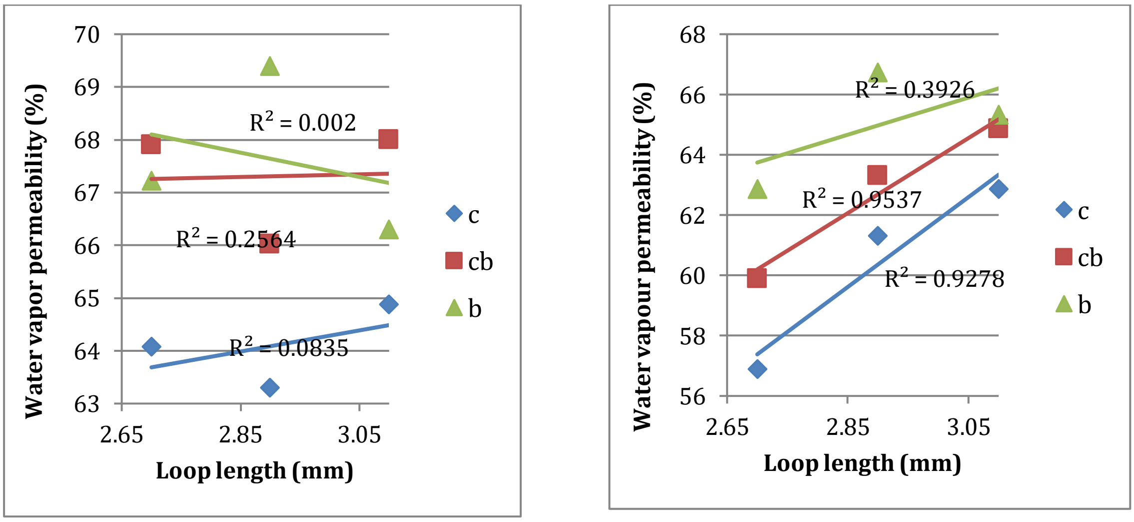
$$Water\ vapour\ permeability = 65.5 + 1.1 * looplength + 4.1 * material - 3.7 * guage$$

R^2=0.92   Equation 2

From equation 2 it could be concluded that a higher loop length which means a looser structure has higher water vapour permeability. Also, the effect of fabric material appears in the equation. Cotton fabric with zero percentage has the lowest water vapour permeability then comes the bamboo/cotton fabric with 70% bamboo and 30% cotton and then comes the 100% bamboo fabric which has the highest water vapour permeability agrees with (6-11).

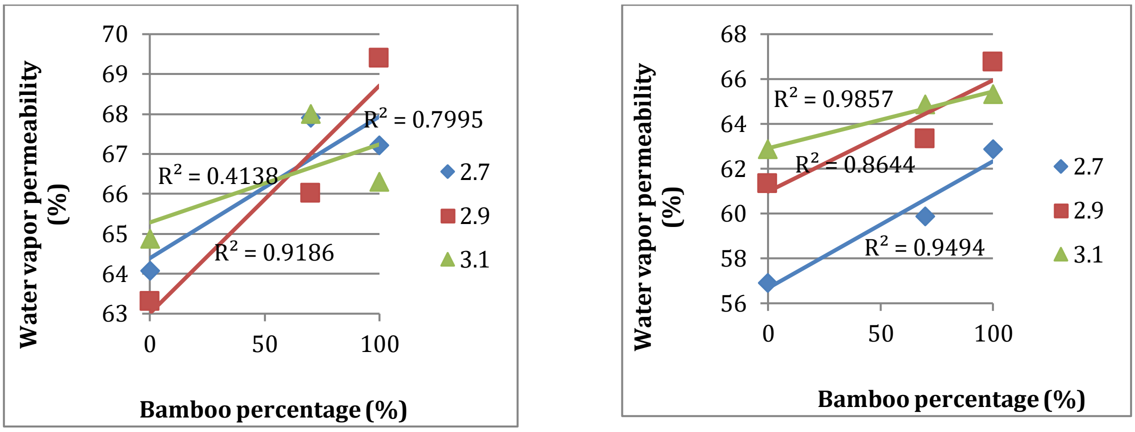
This may be due to the hollow fibre of bamboo cross-section of bamboo which absorbs more water. Machine gauge has negative effect on water vapour permeability which means that fabric produced on gauge 28 (tighter structure) has lower water vapour permeability than fabric produced on gauge 28.

Figures 3(a and b) show the relation between water vapour permeability and loop length for both machine gauges, while figures 4 (a and b) show the relation between water vapour permeability and bamboo percentage for both machine gauges 24 inches, and 28 inches. The figures emphasize the results of equation 2.



(a) **(b)**

Figure. 3. Relation between water vapour permeability and loop length
(a) Gauge 24,(b) gauge 28



(a) **(b)**

Figure. 4. Relation between water vapour permeability and bamboo percentage (a) gauge 24, (b) gauge 28

3.1.3 Thermal resistance

Applying one way ANOVA test for three fabric samples (bamboo, bamboo/cotton, and cotton) for the same stitch length. It was found that there was a significant difference in thermal resistance between bamboo fabric, bamboo/ cotton fabric, and cotton fabric for both machines gauges 24 inches and 28 inches. The p- values are shown in table 5.

Table 5: p- values for differences of thermal resistance between the three fabrics

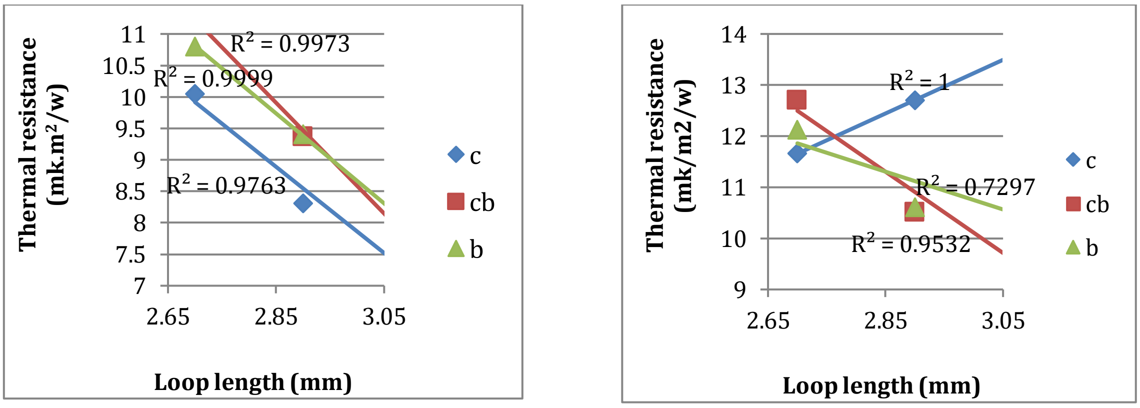
Machine gauge (inches)	Loop length (mm)	P- value
Gauge 24	2.7	0.000144
	2.9	0.000136
	3.1	0.027266
Gauge 28	2.7	0.000296
	2.9	1.84E-08
	3.1	5.91E-11

A stepwise multiple regression analysis was done to predict thermal resistance from fabric constructional and physical parameters.

$$Thermal\ resistance = 8.6 - 0.97 * looplength + 2.45 * gauge \qquad R^2=0.67 \quad \text{Equation } 3$$

From equation 3 it could be concluded that loop length has negative effect on thermal resistance which means that a looser structure with a higher loop length (looser structure) has lower thermal resistance because a loose structure contains more air than tight structure and air has higher thermal resistance than fibres. Fabric produced on gauge 28 has higher thermal resistance than fabric produced on gauge 24 as fabric produced on gauge 24 has a looser structure which leads to lower thermal resistance.

Figures 5(a and b) show the relation between thermal resistance and loop length for both machine gauges 24 inches, and28 inches.



(a) (b)

Figure (5) Relation between thermal resistance and loop length (a) gauge 24,(b) gauge 28

3.1.4 Thermal conductivity

Applying a one-way ANOVA test for three fabric samples (bamboo, bamboo/cotton, and cotton) for the same stitch length. It was found that there was a significant difference in thermal conductivity between bamboo fabric, bamboo /cotton fabric, and cotton fabric for both machine gauges 24 inches and 28 inches. The p- values are shown in Table 6.

Table 6: p- values for differences in thermal conductivity between the three fabrics

Machine gauge (inches)	Loop length (mm)	P- value
Gauge 24	2.7	1.51E-05
	2.9	2.91E-05
	3.1	0.000162
Guage 28	2.7	8.78E-05
	2.9	0.015625
	3.1	0.000116

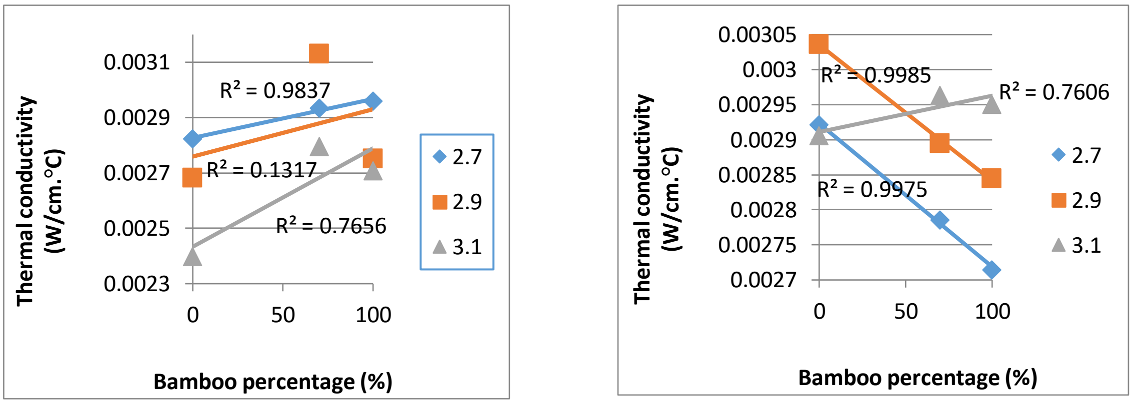
A stepwise multiple regression analysis was done to predict thermal conductivity from fabric constructional and physical parameters.

$$Thermal\ conductivity = -0.003 + 0.014 * thickness + 0.005 * material - 0.011 * thickness * material$$

R^2=0.64 Equation 4

From equation 4 it could be concluded that fibre type and fabric thickness affect thermal conductivity (agrees with 32). Fabric material has a positive significant effect on fabric thermal conductivity. Cotton fabric with zero percentage has the lower thermal conductivity then comes the bamboo cotton fabric with 70% bamboo and 30% cotton and then comes the 100% bamboo fabric which has the higher thermal conductivity. The interaction between fabric thickness and material type has negative effect on thermal conductivity.

Figures 6 (a and b) show the relation between thermal conductivity and bamboo percentage for both machine gauges 24 inches and 28 inches. Figure 6(a and b)emphasizes the results of equation 4.



(a) **(b)**

Figure. 6. Relation between thermal conductivity and bamboo percentage (a) gauge 24,(b) gauge 28

3.1.5 Fabric vertical wicking in wales direction

Applying a one-way ANOVA test for three fabric samples (bamboo, bamboo/cotton, and cotton) for the same stitch length. It was found that there was a significant difference in fabric wick ability in wales direction between bamboo fabric, bamboo/ cotton fabric, and cotton fabric for both machines gauges 24 and 28. The p- values are shown in Table 7.

Table 7: p- values for differences of vertical wicking in wales direction between the three fabrics

Machine gauge (inches)	Loop length (mm)	P- value
Gauge 24	2.7	1.51E-08
	2.9	4.95E-05
	3.1	4.95E-05
Guage 28	2.7	1.15E-05
	2.9	7.41E-05
	3.1	4.8E-07

A stepwise multiple regression analysis was done to predict wick ability in wale direction from fabric constructional and physical parameters.

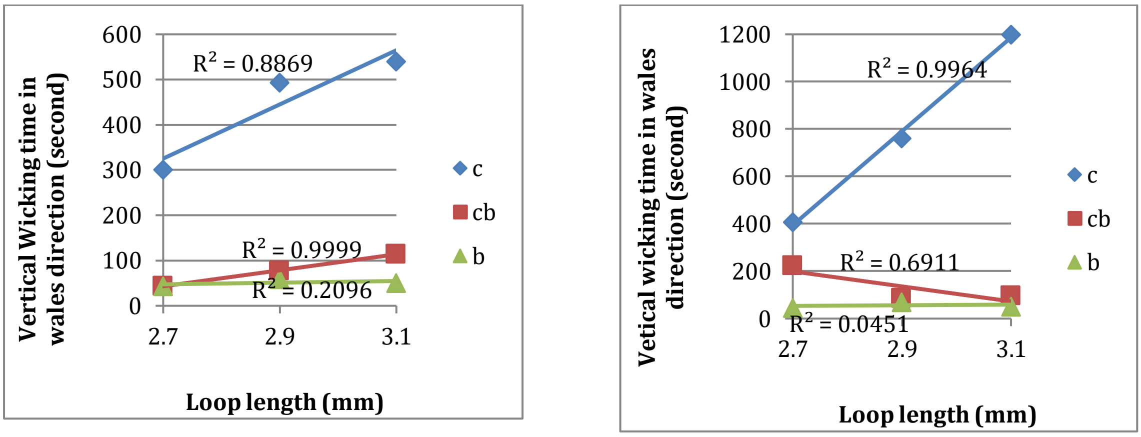
$$Vertical\ wicking\ in\ wales\ direction = 415.5 + 60 * looplength * gauge - 593.2 * material$$

$R^2 = 0.75$ Equation 5

From equation 5 it could be concluded that the interaction between loop length and machine gauge affects fabric wicking time in wale direction positively which means that fabric produced on a machine with gauge 28 with higher loop length (loosest structure) has the highest wicking time in wale direction while fabrics produced on a machine with gauge 24 with lowest loop length (most tight structure) has lowest wicking time in wale direction. The higher loop length improves vertical wicking in wales direction (agrees with 20).Also, the type of material affected the fabric wicking time in wale direction. Cotton fabric with zero bamboo percentage has the lowest wicking time in wales direction then comes the bamboo cotton fabric with 70% bamboo and 30% cotton and then comes the 100% bamboo fabric which has the highest wicking time in wale direction. Which means that bamboo fabric has the highest wicking rate then comes bamboo/cotton fabrics then comes cotton fabrics.

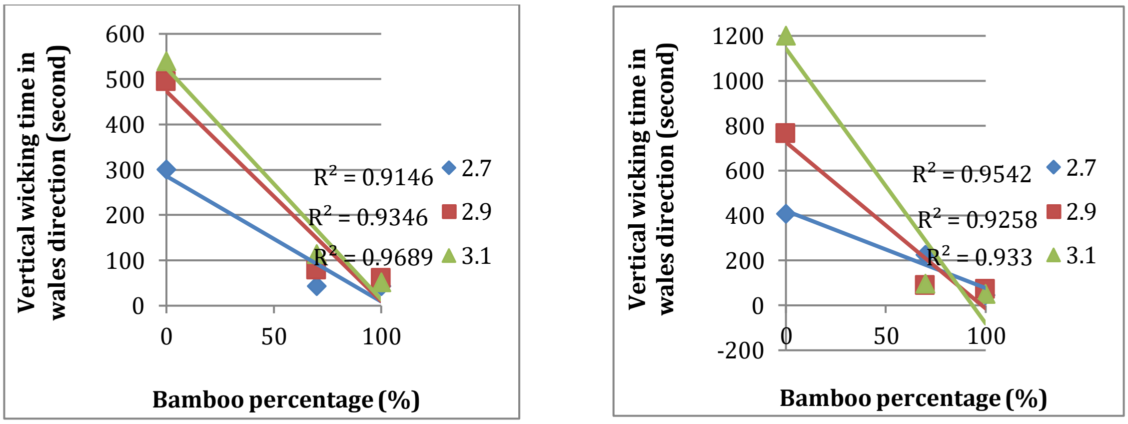
This may refer to the cross-section of bamboo fibre which is known for its hollow cross-section so it is more absorbent to liquids.

Figure 7(a and b) shows the relation between vertical wicking time in wales direction and loop length for three fabrics for both machine gauges 24 inches and 28 inches . It is obvious that there is high correlation between vertical wicking time in wales direction and loop length for cotton and bamboo/cotton fabrics for both gauges which emphasize the effect of loop length on vertical wicking time in wales direction as mentioned in equation 5.



(a) **(b)**

Figure. 7. Relation between vertical wicking time in wales direction and loop length (a) gauge24, (b) gauge28



(a) **(b)**

Figure. 8. Relation between vertical wicking time in wales direction and bamboo percentage (a) gauge24,(b) gauge28

Figures 8 (a and b)show the correlation between vertical wicking time in wales direction and bamboo percentage for the three loop lengths for both machine gauges 24 inches and 28 inches. There are strong inverse correlations between vertical wicking time in wales direction and bamboo percentage for both gauges which emphasize the effect of bamboo percentage in equation 5.

3.1.6 Fabric vertical wicking in course direction

Applying a one-way ANOVA test for three fabric samples (bamboo, bamboo/cotton, and cotton) for the same stitch length. It was found that there was a significant difference in fabric wickability in course direction between bamboo fabric, bamboo cotton fabric, and cotton fabric for both machine gauges 24 and 28. The p- values are shown in Table 8.

Table 8: p- values for differences of vertical wicking in courses direction between the three fabrics

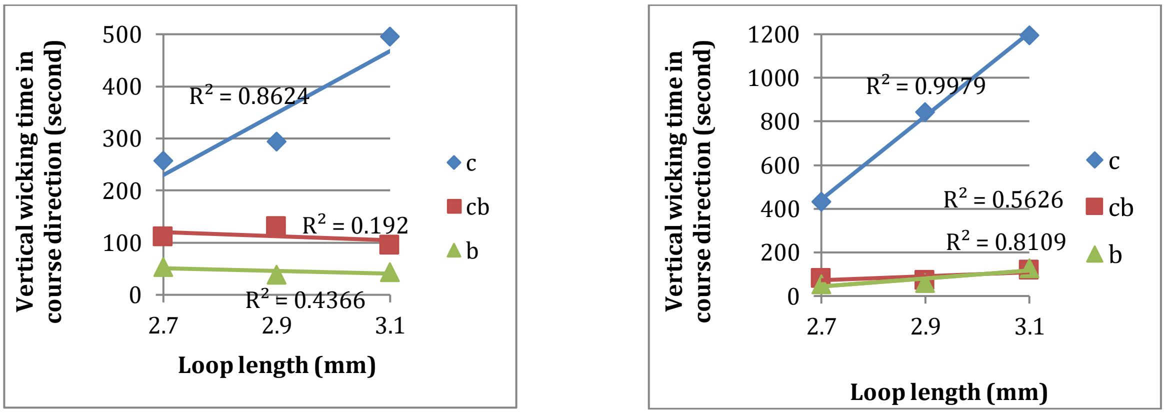
Machine gauge (inches)	Loop length (mm)	P-value
Gauge 24	2.7	0.007996
	2.9	0.000162
	3.1	0.017597
Guage 28	2.7	9.11E-05
	2.9	1.6E-07
	3.1	5.143253

A stepwise multiple regression analysis was done to predict wick ability in weft direction from fabric constructional and physical parameters.

$$Wicking\ in\ courses\ direction = 350 + 71.4 * looplength * gauge - 553.7 * material\ R^2{=}0.72 \qquad \text{Equation 6}$$

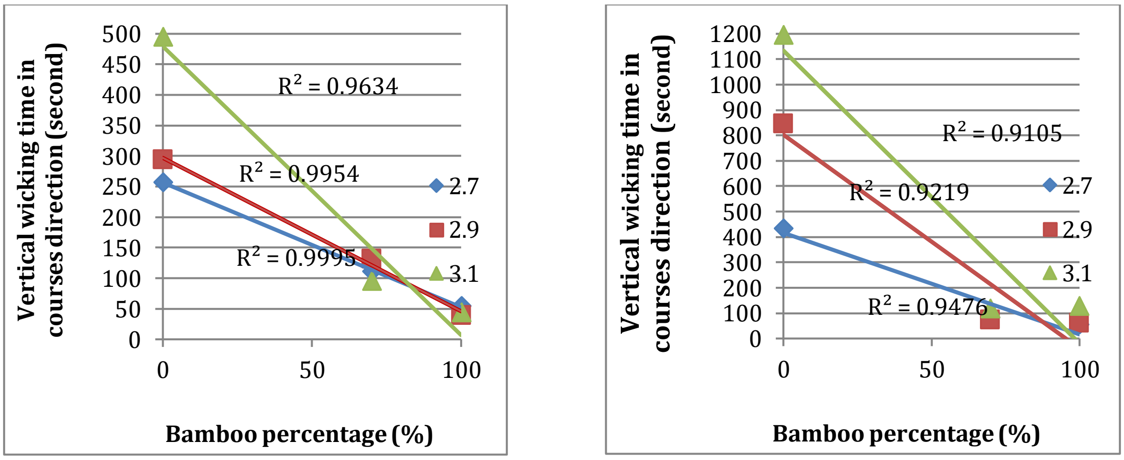
From equation 6 it could be concluded that factors that affect fabric vertical wickability in course directions are the same as in wale directions.

Figures 9 (a and b) show the relation between vertical wicking time in course direction and loop length for three fabrics for both machine gauges 24 inches and 28 inches. There is high correlation between vertical wicking time in courses direction and loop length for cotton and bamboo/cotton fabrics for both gauges which emphasize the effect of loop length on vertical wicking time in courses direction as mentioned in equation 6.



(a) **(b)**

Figure. 9. Relation between vertical wicking time in courses direction and loop length (a) gauge24 , (b) gauge28



(a) **(b)**

Figure. 10. Relation between vertical wicking time in courses direction and bamboo percentage (a) gauge24, (b) gauge28

Figures 10 (a and b) show the correlation between vertical wicking time in wales direction and bamboo percentage for the three loop lengths for both machine gauges 24 inches and 28 inches. There are strong inverse correlations between vertical wicking time in courses direction and bamboo percentage for both gauges which emphasize the effect of bamboo percentage in equation 6.

4. Conclusion

The fibre material affects most of the comfort properties under study significantly. It affects (air permeability, water vapour permeability, thermal conductivity, and vertical wicking rate in both wales and courses direction).

Bamboo fabrics have the highest comfort properties (air permeability, water vapour permeability, thermal conductivity, and vertical wicking rate in both wales and course direction) then bamboo/cotton fabrics then cotton fabric.

Loop length has a positive significant effect on each of the following properties (air permeability, water vapour permeability, vertical wicking in both wales and courses direction), while it has a negative effect on thermal resistance. This means the fabric with higher loop lengths has higher air permeability, water vapour permeability, vertical wicking rate in both wales and course directions, and lower thermal resistance.

Fabric thickness has significant effect on thermal conductivity.

Fabric gauge has a positive effect on thermal resistance. Fabrics produced on a machine with a gauge of 28 inches have a higher thermal resistance. Also, the fabric gauge interacts with loop length in its positive effect on vertical wicking rate in both wales and course direction.

100%Bamboo and bamboo /cotton knitted fabric are preferred for underwear fabrics due to their better comfort properties than cotton fabric.

5. Conflicts of interest

“There are no conflicts to declare”.

6. Formatting of funding sources

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