Improving the thermal comfort properties of bamboo and bamboo blended fabrics for sports head scarves

K. Nassar
Department of Weaving and Spinning, Faculty of Applied Arts, Helwan University, Egypt
Department of Textile Engineering, Faculty of Applied Arts, Badr University, Egypt
khaled.mansour@gmail.com (Corresponding author)
Nahla. M
Department of Weaving and Spinning, Faculty of Applied Arts, Helwan University, Egypt;
Abou-Taleb EM
Department of Weaving and Spinning, Faculty of Applied Arts, Helwan University, Egypt;

Abstract:
In this work, the thermal comfort properties of bamboo & bamboo blended women's head scarves that are worn by females during sports events activities have been investigated. Comfort can be described by the physically relaxed state that is devoid from any pain. Single jersey knitted fabrics samples were produced with the same loop-length from three different types of fibres. The three fibres types were bamboo, cotton, polyester microfiber and their blends with various feeder arrangements. Linear density of bamboo and cotton yarns were 30/1 Ne. Polyester microfiber yarns with Liner density 150 D/144f were used. Results showed that even with same blend ratios, the arrangement of the yarns inside the fabric has an effect on fabric thickness. Moreover, bamboo fabrics scored the lowest weight due to their low specific density, which greatly enhances the comfort levels compared to the other samples. Results obtained show that, Bamboo samples have excelled properties in term of thermal conductivity and Qmax tests compared to other samples.

Keywords:
Thermal Comfort,
Thermal Conductivity,
Bamboo,
Microfiber,
Head Scarves

Paper received 10th July 2020, Accepted 24th August 2020, Published 1st of October 2020

1. Introduction

Headscarves or scarves are fabrics that covers most or all of the top of a woman's hair and her head. Headscarves may be worn for a variety of purposes, such as religious significance, warmth, for fashion, social distinction. Moreover, they can be worn as activewear or sportswear and in that they have to offer high functional properties besides the aesthetic ones. From those properties, thermal comfort emerges as a fundamental function of those types of use. Physiological comfort of an athlete is primarily affected by the worn sports garments, specifically those worn next to the skin, are fundamental to his performance level. [1,2] Comfort can be defined as "a physically relaxed state, without any pain or other unpleasant feelings" [3]. Psychological, tactile and thermal comfort are the three main classification when it comes to clothing comfort. Psychological comfort deals with fashion and social acceptance of clothing. The tactile or sensory comfort deals mainly with how the fabric feels when it comes into close proximity of the wearer skin and is regulated by surface and mechanical properties of the fabric. Thermal regulation of the body temperature is categorized under thermal comfort and is affected by the ability of the fabric to maintain the skin temperature through heat and perspiration regulation. [4] The importance of thermal comfort becomes apparent when studying the importance of maintaining a body temperature of 37°C under all circumstances. Physical activities raise the metabolism of the human body and perspiration increases. Moreover, during elevated activates the human body is capable of producing heat ranges of up to 1000 W. [5] Thus it becomes imperative to maintain a body temperature of 37ºC by transporting the heat away from the body to the environment. [6] Conduction, convection, and radiation, known as dry flux, are the main mechanisms used in heat transport to the environment. Dry flux, namely conduction and convection mechanisms, is used to transfer the perspiration cooling heat flow by direct evaporation of the sweat when there is no direct contact between the skin and the fabric. [5] Fabric thermal isolation is the defining property when dealing with dry flux. On the other hand, latent flux depends on moisture transport management of the used fabric. Accordingly, latent flux is directly linked to effective passage of water vapour and sweat from the skin to the outer surface of the fabric or garment. [1,7,8] Fibre type, spinning technology, yarn linear density, yarn twist, yarn hairiness, fabric thickness, fabric cover factor, fabric porosity and finish mainly influence the thermal comfort properties of fabrics. [9,10] Both natural and synthetic fibres are used in sportswear. Moreover, the evolution of fiber developments went from the phases of traditional fibers, highly functional fibers in addition to high performance fibers. Among all fibres used in active and sportswear, polyester is the single most used one. [11,12]

Although Polyester fibres are known for their hydrophobicity when compared to cotton fibres, their wicking rate is superior to cotton fibres. They are also cheap and easy to handle.[12]

In its unfinished state, polyester fiber is hydrophobic and has a much lower water absorption capacity than, for example, cotton fiber, but its wicking rate, although slow compared with some other synthetic fibers, is faster than that of cotton. Polyester fiber is also cheap to manufacture and easy to care for and has excellent washing and wearing properties. Manmade fibres like polyesters and nylons have the ability to be produced in microdenier counts. [13] It is also observed that the thermal conductivity, thermal absorptivity and maximum heat flux values are higher for microfiber fabrics when compared to non-microfibre fabrics. On the other hand, microfiber fabrics showed lower thermal resistance and thermal diffusivity values. The higher thermal absorptivity and maximum heat flux values results in the fact that fabrics from microfibers provide cooler feeling when in contrast with those from standard fibers. [14] Of all the advantages of polyester fibres, the fact remains that is not obtained from renewable resources, neither it biodegradable. On the other hand, bamboo is both biodegradable and made from renewable resources. Bamboo is classified as a regenerated fibre and when compared to other well-known regenerated fibres such as lyocell and rayon it growing cycle is much shorter and efficient and resistant to pests [15] Moreover, bamboo is breathable, cool to touch, antimicrobial and very soft to the touch. In comparison to cotton fibres it absorbs more water. [16,17] Knitted garments are known to exhibit great comfort properties. They not only allow for ease of movement and excellent stretch ability, they also have great handle and facilitate easy transmission of water vapour from the body. Moreover, they are characterized by uneven surface which in turn lessens the number of contact points between the fabric and the skin which in turn a more pleasant tactile sensation compared to other textile structures. [9,18,19]

2. Materials and Methods

2.1 Materials

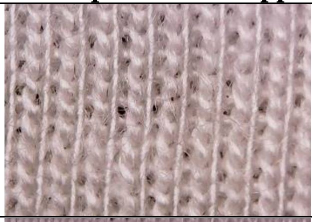
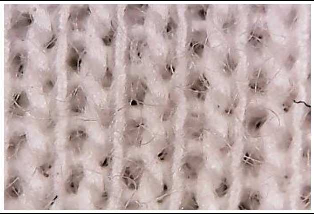
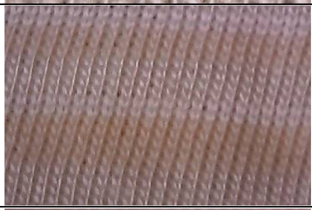
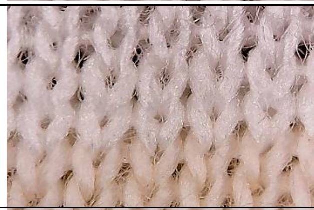
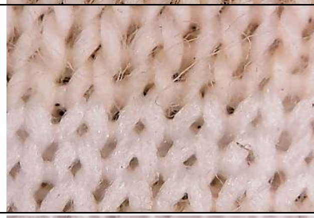
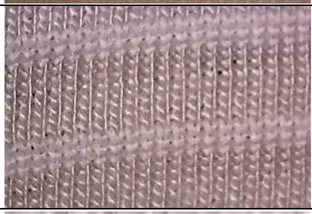
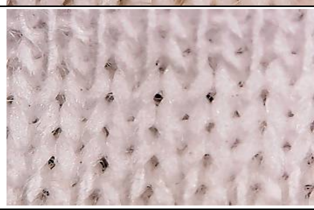
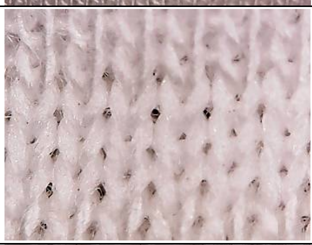
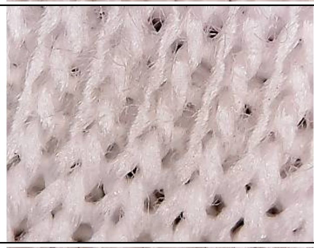
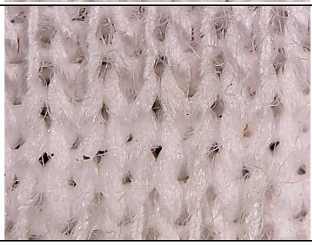
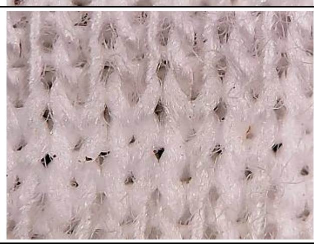
Knitted fabric samples were produced using a plain knitting machine (single jersey Machine). All Samples have the same loop-length from three different types of fibres namely, bamboo, cotton, polyester microfiber and the blends thereof, were used for the study. Blends of different materials were obtained by different arrangement of the machine feeders' yarn. The machine has 26 feeders, which were arranged as shown in Table (1).

Table 1 Samples composition

Sample No.	Composition	Yarn Feeders Arrangement							Total fabric composition		
		BA	CO	PET	BA	CO	PET	Total	BA	CO	PET
1	BA	26	---	---	---	---	---	26	100%		
2	BA/ CO / PET	4	3	2	10	5	2	26	54%	31%	15%
3	CO /PET	---	7	3	---	13	3	26	---	77%	23%
4	BA/PET	20	---	6	---	---	---	26	77%	---	23%
5	CO/PET	---	20	6	---	---	---	26	--	77%	23%
6	BA/PET	7	---	3	13	---	3	26	77%	--	23%
BA --- Bamboo Co --- Cotton PET Polyester Micro fiber											

From Table (1) it can be seen that: sample no 3 and sample no 5 have the same fiber composition of 77% Co & 23% PET but with different yarns arrangement also samples no 4 and no 6 were of the same composition but shared different yarn arrangement. Linear density of Bamboo and Cotton yarns were the same 30/1 Ne. Polyester microfiber yarn with Liner density 150 Den/144f. Moreover, Table (3) depicts the samples surface appearance under a digital microscope.

Table 2 Samples surface appearance under digital microscope

Sample No. 1		
Sample No. 2		
Sample No. 3		
Sample No. 4		
Sample No. 5		
Sample No. 6		

2.2 Methods

Before the testing, the samples were were placed in tension free state on a flat surface at room conditions for 48 hours. A standard atmosphere of 21 °C ± 1 and relative humidity of 65% ± 2 were maintained in the room.

The number of courses & wales per cm, mass per unit area and thickness of the fabric samples were measured according to the relevant standards. The mass per unit area of the fabric was calculated according to ASTM D 3776-96 and fabric thickness was calculated according to ASTM D 1777-07. The number of courses and wales per cm was calculated according to *ISO 7211-2*:1984. A Thermo Lab KES 7 was used to evaluate the fabric thermal conductivity and QMAX values.

To conclude whether the parameters were significant or not, p values were examined through ANOVA (analysis of variance) at a 95% confidence level to measure the significance of fabric composition parameters on thickness, weight, thermal conductivity, and QMAX of the knitted fabrics.

3. Results and discussion

It is well known that, the thermal conductivity and the sensorial comfort through fabrics are probably the most important factors in sportswear. Results of the experimental tests carried out on samples under study are set out in the Table 3 and figure 1. Results were also statistically analyzed for data listed and relationships between variables were obtained.

Table (3) Samples specification and test results

Sample No	Fabric Composition	Thickness (mm)	Weight (g/m^2)	Wales/ cm	Course/cm	Thermal cond. (mW.d/a.Δt)	QMAX (w)
1	BA	0.38	133.7	13.3	17.8	0.293	0.105
2	BA/CO/PET	0.38	136.6	14	17	0.276	0.100
3	CO/PET	0.41	143.4	13.75	17.7	0.260	0.098
4	BA/PET	0.37	134.5	13.7	17	0.279	0.100
5	CO/PET	0.39	137.0	14.3	17	0.266	0.091
6	BA/PET	0.39	134.2	13.7	18	0.276	0.099

3.1 Effect of different fabric composition on fabric thickness

The results of the thickness determination are listed in Table (3) and shown in Figure (1). The results show that, there is a variance between the thicknesses of all samples and the results proved to be significant which may be attributed to the difference between the yarn material and composition of all fabrics.

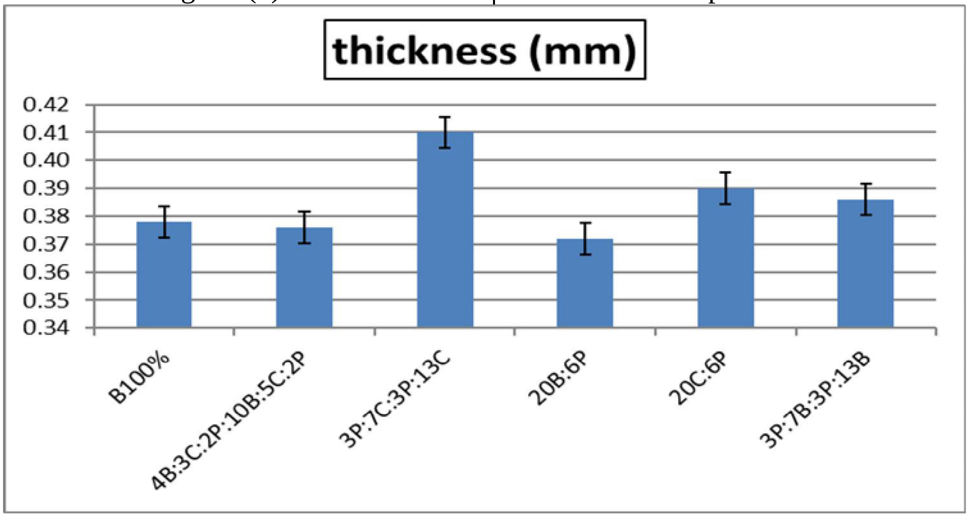


Fig. (1) Effect of different fabric composition on fabric thickness

Although samples (3) and (5) have the same blend ratio between cotton and polyester microfibers, and samples (4) and (6) have the same blend ratio between bamboo and polyester microfibers, they have different thicknesses. After analyzing the ANOVA results for the thickness of samples (3) and (5) and samples (4) and (6) as listed in Tables (4) and (5), the difference was found to be significant for samples (3) and (5) and also for samples (4), (6) where ($P \leq 0.05$). Moreover, from Figure (1) it can be seen that sample (3) scored the highest thickness of 0.41 mm in comparison to all other samples. This difference may be attributed to the different stripe width created by the different distribution of the yarns in samples (3) and (6) when compared to stripes width in (5) and (4) respectively as shown in Table (1). This difference in material distribution in the samples, even with sharing the overall same blending ratio, causes differences in yarn tension which in turn leads to a variance in fabric thickness.

Table (4) ANOVA statistical analysis of fabric composition on fabric thickness for samples 3 and 5

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.001	1	0.001	20	0.002077	5.317655
Within Groups	0.0004	8	5E-05			
Total	0.0014	9				

able (5) ANOVA statistical analysis of fabric composition on fabric thickness for samples 4 and 6

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.00049	1	0.00049	9.8	0.014005	5.317655
Within Groups	0.0004	8	5E-05			
Total	0.00089	9				

3.2 Effect of different fabric composition on fabric weight

The results of the weight determination are listed in Table (3) and shown in Figure (2). After reviewing the results, it can be observed that there is a variance in sample weights of all samples.

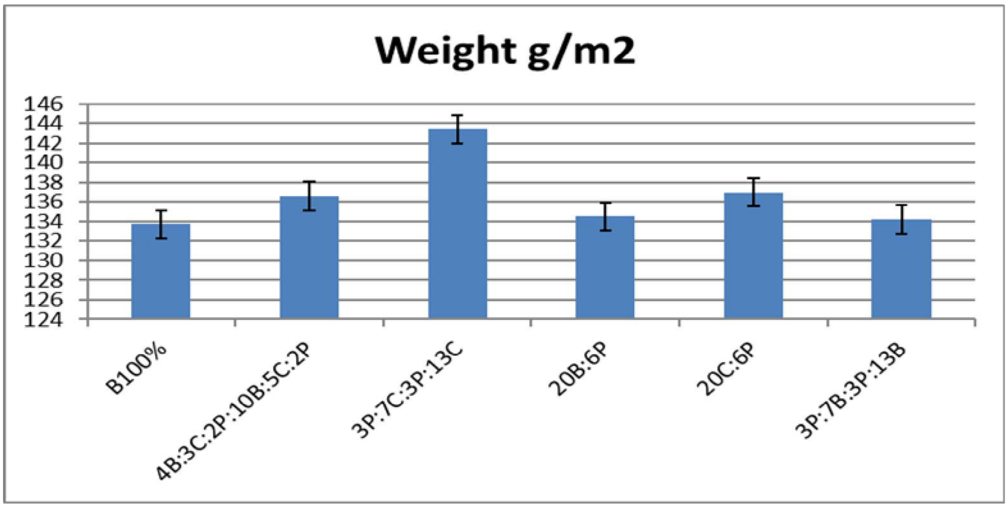


Fig. (2) Effect of different fabric composition on fabric wiegth

After further examination it was found that sample (3) recorded the highest weight of 143.4 g/m2 when compared to the rest of the samples. On the other end of the spectrum, sample (1) recorded the least weight of 133.7 g/m^2 and the difference was found to be significant where (P≤ 0.05) as listed in Table (6) That can be attributed to the difference in the specific density of the samples materials where the increase in specific density of fibers leads to an increase in fibres weight and ultimately in fabric weight. Accordingly, by reviewing the specific density of bamboo, polyester and cotton which are 1.54, 1.38 and 0.8 g/cm^3 respectively it can be found that weight of the sample (1) made of 100% bamboo scored the lowest weight followed by polyester and cotton samples respectively.

Table (6) ANOVA statistical analysis of fabric composition on fabric weight

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	141.135	1	141.135	1129.08	4.68E-06	7.708647
Within Groups	0.5	4	0.125			
Total	141.635	5				

3.3 Effect of different fabric composition on thermal conductivity

Table (3) and figure (3) show the thermal conductivity of the reviewed samples and ANOVA results show that fabric composition has a significant effect on the thermal conductivity where (P≤ 0.05) as listed in Table (7)

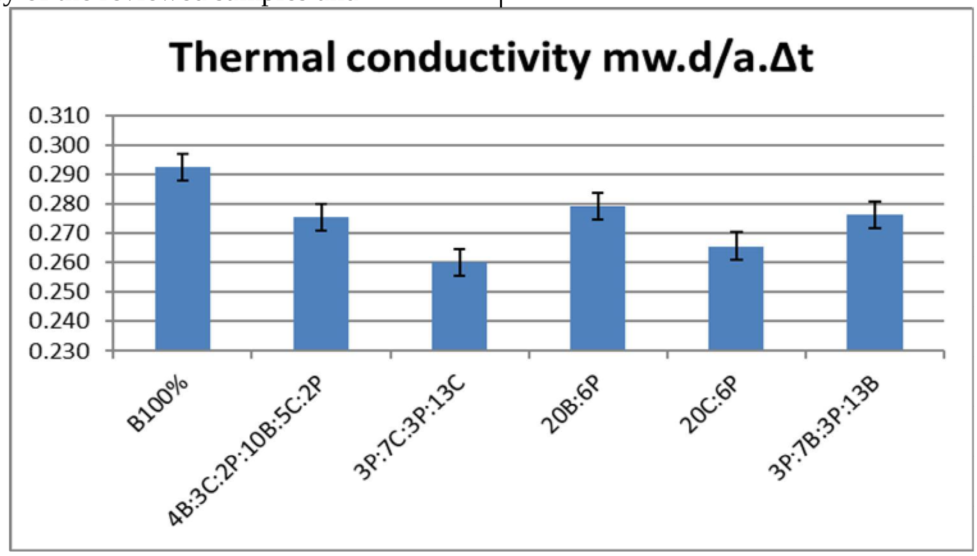


Fig. (3) Effect of different fabric composition on thermal conductivity

Table (7) ANOVA statistical analysis of fabric composition on thermal conductivity

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	**0.001438154**	**1**	**0.001438**	**154.9188**	**0.00024**	**7.708647**
Within Groups	**3.71331E-05**	**4**	**9.28E-06**			
Total	**0.001475287**	**5**				

Furthermore, sample (1) of 100% bamboo fabric has the highest thermal conductivity, followed by blended bamboo/polyester microfibers, then blended bamboo/polyester microfibers/cotton respectively. On the other hand, sample (3) made of blended cotton /polyester microfibers recorded the least thermal conductivity.

The results of thermal conductivity can be explained by reviewing fibre morphology and its effect on contact areas between fabrics and skin. As for the morphology, Bamboo and polyester microfibers are less hairy compared to equivalent cotton fibres.[20] Moreover, the contact areas between fabrics and skin in bamboo and polyester microfibers are more than that of the cotton. This may be attributed to the uniform cross section of bamboo fibers and the finesse of polyester microfibers when compared to cotton fibres which have a ribbon like longitudinal section and a kidney bean shaped cross section.

3.3 Effect of different fabric composition on fabric QMAX

The results of fabrics QMAX for all samples are tabulated in Table (3) and shown in Figure (5). It can be observed that fabric composition has a significant effect on QMAX results as shown in Table (8) where ($P \leq 0.05$). Sample (1) recorded the highest value of QMAX, followed by blended bamboo/polyester microfiber, then blended bamboo/polyester microfiber/cotton. On the other hand, sample (5) of blended cotton/polyester microfiber recorded the lowest QMAX. That relates to the maximum value of heat flux during a contact to warm-cool feeling felt when the fabric touches skin. The difference may be attributed to the variance of the hygroscopicity for fabrics' materials. [20] As the cross-section of the bamboo fiber is filled with various micro-gaps and micro-holes, it has much better moisture absorption and ventilation. Moreover, polyester microfiber is super-absorbent, absorbing over seven times their weight, through wicking because a large number of capillary tubes between fibers are formed in yarn cross section thus leading to better wickability.

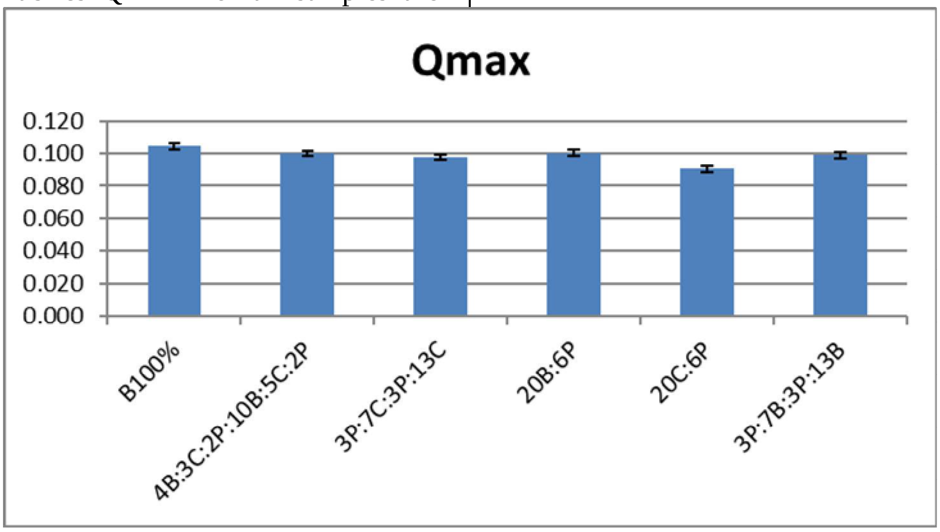


Fig. (5) Effect of different fabric composition on QMAX test result

Table (8) ANOVA statistical analysis of fabric composition on QMAX

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	**0.000294**	**1**	**0.000294**	**113.8065**	**0.000437**	**7.708647**
Within Groups	**1.03E-05**	**4**	**2.58E-06**			
Total	**0.000304**	**5**				

4. Conclusion

The thermal comfort properties of 100% bamboo, cotton bamboo polyester microfiber, bamboo polyester microfiber and cotton polyester microfiber blended fabric single jersey fabrics were investigated in this study. In general, the thermal comfort properties of the fabrics depend on their fiber content. The presence of bamboo fiber in the fabric proved to have a positive effect on the thermal comfort properties. The 100% bamboo fabric was found to have the highest thermal conductivity, with the lowest being for cotton polyester fabric. Moreover, 100% bamboo fabric has higher thermal conductivity than bamboo polyester microfiber fabric. Additionally, the arrangement of the yarns inside the fabric plays a vital part in controlling the fabric thickness. This combined with the low weight of bamboo samples indicates that bamboo fibres can act as a competitive substitute to cotton and microfiber polyester in the field of sportswear and specifically sports head scarves.

Author statement

Abou-Taleb EM: conceptualization, writing - original draft preparation, analysis, statistics, writing results and discussion; Nahla M.: methodology, sample preparation, writing results and discussion; K. Nassar: supervisor, Writing-Reviewing and Editing.

Acknowledgement

Authors are grateful to the National Research Centre for facilities provided.

References

[1] V.K. Kothari, P. Sanyal, Fibres and fabrics for active sportswear, ASIAN Text. J.-BOMBAY-. 12 (2003) 55–61.
[2] Q. Zhuang, S.C. Harlock, D.B. Brook, Transfer wicking mechanisms of knitted fabrics used as undergarments for outdoor activities, Text. Res. J. 72 (2002) 727–734.
[3] COMFORT (noun) definition and synonyms | Macmillan Dictionary, (n.d.). https://www.macmillandictionary.com/dictionary/british/comfort_1 (accessed April 2, 2020).
[4] M. Senthilkumar, M.B. Sampath, T. Ramachandran, Moisture management in an active sportswear: techniques and evaluation—a review article, J. Inst. Eng. India Ser. E. 93 (2012) 61–68.
[5] L. Hes, M. de Araujo, Simulation of the effect of air gaps between the skin and a wet fabric on resulting cooling flow, Text. Res. J. 80 (2010) 1488–1497.
[6] R. Angelova, Textiles and human thermophysiological comfort in the indoor environment, 2015. https://doi.org/10.1201/b19118.
[7] C.-I. Su, J.-X. Fang, X.-H. Chen, W.-Y. Wu, Moisture Absorption and Release of Profiled Polyester and Cotton Composite Knitted Fabrics, Text. Res. J. - TEXT RES J. 77 (2007) 764–769. https://doi.org/10.1177/0040517507080696.
[8] A. Das, R. Alagirusamy, 6 - Moisture transmission, in: A. Das, R. Alagirusamy (Eds.), Sci. Cloth. Comf., Woodhead Publishing India, 2010: pp. 106–135. https://doi.org/10.1533/9780857092830.106.
[9] C. Prakash, G. Ramakrishnan, C.V. Koushik, A study of the thermal properties of bamboo knitted fabrics, J. Therm. Anal. Calorim. 111 (2013) 101–105.
[10] Effect of yarn properties on thermal comfort of knitted fabrics | Request PDF, (n.d.). https://www.researchgate.net/publication/229169486_Effect_of_yarn_properties_on_thermal_comfort_of_knitted_fabrics (accessed April 2, 2020).
[11] R. Shishoo, Textiles in sport, Elsevier, 2005.
[12] S.C. Higgins, M.E. Anand, Textiles materials and products for active wear and sportswear, Tech. Text. Mark. 52 (2003) 9–40.
[13] H.K. Kaynak, O. Babaarslan, Polyester Microfilament Woven Fabrics, Woven Fabr. (2012). https://doi.org/10.5772/38483.
[14] A.D. Gun, Dimensional, physical and thermal comfort properties of plain knitted fabrics made from modal viscose yarns having microfibers and conventional fibers, Fibers Polym. 12 (2011) 258–267. https://doi.org/10.1007/s12221-011-0258-2.
[15] N. Erdumlu, B. Ozipek, Investigation of regenerated bamboo fibre and yarn characteristics, Fibres Text. East. Eur. 16 (2008) 69.
[16] F. Sekerden, Investigation on the Unevenness, Tenacity and Elongation Properties of Bamboo/Cotton Blended Yarns, Fibres Text. East. Eur. 86 (2011) 26–29.
[17] P. C, K. Saravanan, Bamboo fibres & their application in textiles, " Indian Text. J. CXVIII (2008) 137–140.
[18] V.T. Bartels, Physiological comfort of sportswear, in: Text. Sport, Elsevier, 2005: pp. 177–203.
[19] Y. Li, A.S. Wong, Clothing biosensory engineering, Woodhead Publishing, 2006.
[20] G. Karthikeyan, G. Nalankilli, O.L. Shanmugasundaram, C. Prakash, Thermal comfort properties of bamboo tencel knitted fabrics, Int. J. Cloth. Sci. Technol. 28 (2016) 420–428. https://doi.org/10.1108/IJCST-08-2015-0086.