Daiva Mikučionienė,
Edgaras Arbataitis

Kaunas University of Technology,
Department of Textile Technology
Studentu 56, LT-51424 Kaunas, Lithuania
E-mail: daiva.mikucioniene@ktu.lt

Comparative Analysis of the Influence of Bamboo and Other Cellulose Fibres on Selected Structural Parameters and Physical Properties of Knitted Fabrics

Abstract
This study attempts to investigate the influence of different cellulose yarns on the structure and physical properties of knitted fabrics, such as loop length, wale and course spacing, the loop shape factor, the area density of knits, etc. In this work, the behaviour of man-made bamboo yarns and knits in comparison with other cellulose yarns is presented. It is stated that the prediction of the physical properties of knits from new generation fibres in accordance with widely investigated common fibres is incorrect without appropriate experiments. It was found that man-made bamboo knits are similar to cotton knits considering geometrical and structural properties and are similar to viscose fibres taking into account some physical properties. The physical reasons of these similarities and differences are discussed.

Key words: *man-made bamboo yarns, viscose yarns, cotton yarns, loop length, wale spacing, course spacing, loop shape factor, air permeability.*

Introduction

In recent years, new types of fibres and yarns have been proposed on the market. The physical properties of fibres are usually simply superimposed on the physical properties of textile fabrics, commonly without comprehensive structural investigations. However, the structure of textile fabrics influences their physical properties as well.

Man-made fibres of natural raw material origin, such as casein, soy-bean and bamboo fibres are very popular and recently more and more widely used. Their properties and processing behaviour are compared and often predicted based on widely investigated fibres.

The structural parameters of knitted fabrics, the majority of their mechanical and physical properties, depend on the technical characteristics of knitting machines, on the properties of yarns such as the linear density and twist level of yarn, as well as on the origin of raw material of fibres. Commonly the different physical properties of fabrics knitted from cotton, viscose or man-made bamboo yarns are highlighted and specific properties such as antibacterial, absorptive, antipilling and others are underlined. Natural bamboo fibres, which means bast fibres, are commonly compared with ramie fibres, whereas man-made bamboo fibres with viscose fibres [1 - 6]. Today, however, the behaviour of yarns of different origin during knitting is rarely investigated.

During the manufacturing process, yarns move on the various parts of the knitting machines, such as needles, guides, lease rods, heald shafts etc. Because of these motions, yarns are turned, pressed and flexed. Yarn tension is the result of these influences and, in turn, the value of this also depends on yarn friction properties. These properties strongly depend on the raw material used for yarn production [7 - 12]. The main factor influencing all dynamic friction characteristis is yarn stress. But there are many different factors which are of great significance for the friction characteristic thatdepend on moisture and temperature, on the twist of the yarn explored, surface greasiness, the friction body, bending angle, yarn roughness, moving speed, electrostatic properties, etc. [7, 8]. Mikołajczyk [9, 10] investigated the relations of changes in the parameters of the knitting process on warp-knitting machines depending on the rheological properties of threads modified and accented, being research problems of the knitting process in the aspect of the structural properties of machines that are often ignored in literature.

The length of yarn drawn into the loop depends on the depth to which the needle sinks below the verges and on the yarn tension at the point of full depression [13, 14]. It means that the main loop parameters such as wale and course densities, the area density, tightness factor, etc. depend on the friction properties and tension of the yarn used during the knitting process. All these parameters and many others are also affected by the yarn linear density (number or yarn count). Čiukas and Abramavičiūtė in [13] stated that the porosity of the knit is affected by the linear density of yarn and the lenght of the loop. It was stated that knits from cotton and bamboo yarns give different permeability to air and water vapour, and have different water absorbtion and thermal properties [15 - 17].

Therefore the behaviour of different types of cellulose yarns and herewith the properties of fabrics manufactured from them are not the same. Due to that, it is unwarranted to use well-known results of investigations concerning cotton or viscose yarns and to use them for the property prediction of fabrics from other kinds of cellulose yarns. The comparative analysis of the properties and behaviour of fabrics from different types of cellulose yarns becomes very important, but studies in this field are not sufficient. Especially not fully clarified are the properties of products produced from man-made bamboo cellulose (fibres, yarn, knitted and woven fabrics).

Therefore the main goal of this study was to compare the structural parameters of fabrics knitted from man-made bamboo, viscose and cotton yarns and to establish their influence on selected physical properties of knits. For investigation we chose the air permeability of knitted fabrics, as it strongly depends on their structural parameters.

Materials and methods

Experiments were carried out with cotton, viscose and man-made bamboo yarns with a 19.5 tex linear density and 227 t.p.m. twist factor. Such yarns are regularly used in knitting processes for various textile products. Cotton is the most widely used natural cellulose fibre, viscose is a well-known and widely used man-made cellulose fibre, and bamboo fibre as man-made cellulose fibre is more and more popular and currently widely used fibre. Twelve variants of fabrics were knitted from these yarns in a single jersey knitting pattern on the same 14E gauge of a one needle-bed circular weft-knitting machine. The single jersey pattern was chosen because it is a simple and widely investigated structure. The main characteristics of the knitted fabrics investigated are presented in ***Table 1***. The same set of the knitting machine was used for all variants, i.e. the parameters of knitting were not changed, only the type of yarns and the number of yarns in the loop. All knitted samples were divided into three groups according to the raw material of yarns used. In each group four variants of knits were prepared differing in the number of yarns in one loop (1, 2, 3 & 4 yarns with linear density 19.5 tex). The different number of yarns in one loop was chosen in order to check whether in all possible cases of the knits selected, the influence of the raw material of yarn on the main structural parameters of knits is visible.

All experiments were carried out in a standard atmosphere provided for testing according to Standard EN ISO 139:2005. All knitted fabrics were investigated in a “grey” state, i.e. without finishing, but after 1-week relaxation in a free state in standard atmospheric conditions.

The structure parameters of the knitted samples, such as the actual loop length l, wale P_w and course density P_c were analysed according to British Standard BS 5441:1998. The course and wale density were counted in the length and crosswise directions of the knits over a 10 cm distance and evaluated per 1 cm. The actual loop length was measured by the unknitting method. The pretension of unknitted yarn during the measurment was 0.02 cN/tex. The area density M, wale course spacing, (A & B, respectively), and loop shape factor C were calculated according to the formulas presented below (1) – (4)

$$M = P_w \cdot P_c \cdot l \cdot T \cdot 10^{-2}, \text{ in g/m}^2; \quad (1)$$

where M is the area density in g/m^2, P_w the wale density in cm^{-1}, P_c the course density in cm^{-1}, l the loop length in mm, and T is the yarn linear density in tex.

$$A = \frac{10}{P_w}; \text{ , in mm} \quad (2)$$

$$B = \frac{10}{P_c}; \text{ , in mm} \quad (3)$$

$$C = \frac{B}{A}; \quad (4)$$

Tensile properties of the yarns were determined using an universal tensile tester ZWICK/Z005. The stress-strain characteristics of the yarns studied were obtained in accordance with Standard LST EN ISO 2062:2010. The tensile strength of yarn is an important parameter in assessing yarn quality. Considering knitting, yarn strength is not so important because in this process the yarn is not subjected to very great loads. During the bending of loops, they undergo stresses of approximately 0.5 - 1.5 cN/tex. The initial modulus of elasticity is much more important for the prediction of yarn behavior during knitting, which in our case was estimated in cN/tex on the basis of the initial part of the stress-strain curves.

The coefficient of friction μ was determined when investigating the friction of yarn on a 2 mm diameter needle at a speed of 0.10 m/s [8]. The coefficient of friction was calculated according to the Euiler formula:

$$T_2 = T_1 e^{\mu\varphi} \quad (5)$$

$$\mu = \ln(T_2/T_1)/\varphi \quad (6)$$

where μ is the coefficient of friction, T_2 the output yarn tension, T_1 the input yarn tension, and φ is the yarn bending angle (180°).

The tests were performed on equipment as described in [8].

Air permeability tests of the knitted fabrics investigated were conducted according to Standard EN ISO 9237:1997. For a sample area of 10 cm^2 and pressure difference of 100 Pa 10 tests per sample were performed. The air permeability R was determined according to the following equation:

$$R = \frac{D}{A} \cdot 167; \quad (7)$$

where R is air permeability in dm^3/(m^{2}s), D the average of the air flow rate, dm^3/min, and A is the sample operative area - 10 cm^2.

Table 1. *Main characteristics of knits.*

Sample code	Raw material and linear density of yarn, tex	Wale density P_w, cm^{-1}	Course density P_c, cm^{-1}	Actual loop length l, mm	Area density M, g/m^2
C1	Cotton 19.5	9.0 ± 0.05	8.0 ± 0.05	4.78 ± 0.09	67.1
C2	Cotton 19.5×2	8.30 ± 0.05	9.50 ± 0.05	5.04 ± 0.08	155.0
C3	Cotton 19.5×3	8.0 ± 0.05	10.0 ± 0.05	5.20 ± 0.08	243.4
C4	Cotton 19.5×4	7.90 ± 0.05	11.0 ± 0.05	5.28 ± 0.09	357.9
B1	Man-made Bamboo 19.5	8.80 ± 0.05	7.85 ± 0.05	4.80 ± 0.08	64.7
B2	Man-made Bamboo 19.5×2	8.45 ± 0.05	9.25 ± 0.05	5.12 ± 0.09	156.1
B3	Man-made Bamboo 19.5×3	8.35 ± 0.05	9.95 ± 0.05	5.20 ± 0.00	252.7
B4	Man-made Bamboo 19.5×4	8.10 ± 0.05	10.50 ± 0.05	5.28 ± 0.06	350.3
V1	Viscose 19.5	8.90 ± 0.05	7.80 ± 0.05	4.96 ± 0.08	67.1
V2	Viscose 19.5×2	8.35 ± 0.05	8.90 ± 0.05	5.08 ± 0.09	147.2
V3	Viscose 19.5×3	8.20 ± 0.05	9.50 ± 0.05	5.18 ± 0.06	236.1
V4	Viscose 19.5×4	8.0 ± 0.05	10.50 ± 0.05	5.26 ± 0.07	344.6

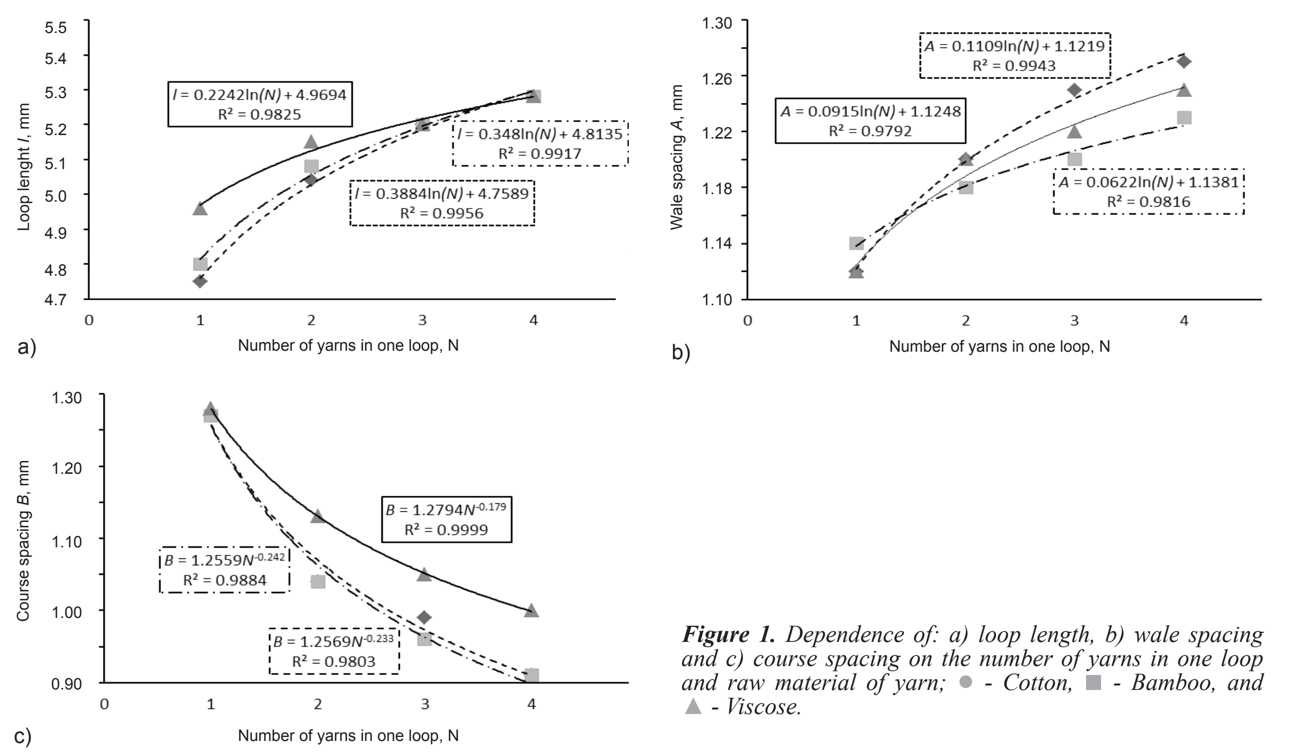

Figure 1. *Dependence of: a) loop length, b) wale spacing and c) course spacing on the number of yarns in one loop and raw material of yarn; ● - Cotton, ■ - Bamboo, and ▲ - Viscose.*

Results and discussions

Twelve variants of knitted fabrics from one, two, three and four cotton, man-made bamboo and viscose yarns were knitted. Their characteristics are presented in ***Table 1***. The calculated loop length results presented in ***Figure 1.a*** demonstrate that by increasing the yarn count (linear density) in one loop, the loop length increased. The physical reason for the logarithmic relationship, which describes well the behaviour of the loop length depending on the yarn number in the loop, is that by increasing the number of yarns in one loop, the influence of the yarn number on the loop length gradually decreases until the structure of the knit is fully interspaced. In addition, these results show that the values of loop length of knits from particular yarn of raw material differ, regardless of the fact that they are knitted on the same knitting machine and with the same yarn linear density. Viscose knits have longer loops than cotton and man-made bamboo ones. This difference is best visible for knits with a lower yarn linear density and looser structure, i.e. for those knitted from one or two yarns.

In ***Figures 1.b*** and ***1.c***, the dependences of wale spacing and course spacing on the number of yarns in one loop and on the raw material of the yarns are presented. The wale spacing can be interpreted as the width of one wale, which primarily depends on the knitting machine gauge, i.e. on the number of needles in one inch. As is shown in ***Figure 1.b***, the wale spacing also depends on the number of yarns in one loop (the total linear density of yarns) – when the number of yarns increases the wale density increases too. However, by increasing the number of yarns in one loop the influence of the number of yarns on wale spacing decreases. In this case, the influence of the raw material on wale spacing becomes apparent in the higher total linear density of the yarns: cotton knitted fabrics have the highest wale spacing and man-made bamboo – minimal wale spacing.

The number of yarns in one loop influences the course spacing as well. The depth of loop sinking and the take-up force (during the knitting, the pneumatic take-up force was kept the same for all samples) determine this parameter. The results presented in ***Figure 1.c*** show that the number of yarns in one loop and the raw material of the yarn influence the course spacing. However, the influence of the raw material on the course spacing has a different character from wale spacing. The course spacing in viscose knits is higher than in cotton and man-made bamboo knits - the latter two knits have practically the same course spacing.

The difference in loop sinking and loop length as well as in course spacing may be explained by yarn friction properties. Values of the static and dynamic coefficients of friction of cotton, man-made bamboo and viscose yarns are presented

Table 2. *Static and dynamic coefficients of friction.*

Yarns l	Static coefficient of friction μ_S	Dynamic coefficient of friction μ_D
Cotton 19.5 tex	0.29	0.22
Man-made bamboo 19.5 tex	0.29	0.21
Viscose 19.5 tex	0.26	0.18

Table 3. *Tensile strength parameters of yarns.*

Yarn	Tenacity f, cN/tex	Elongation at break ε, %	Initial elasticity modulus *E*, cN/tex
Cotton 19.5 tex	13.53	4.16	2.356
Man-made bamboo 19.5 tex	14.32	12.91	2.747
Viscose 19.5 tex	10.64	10.92	1.376

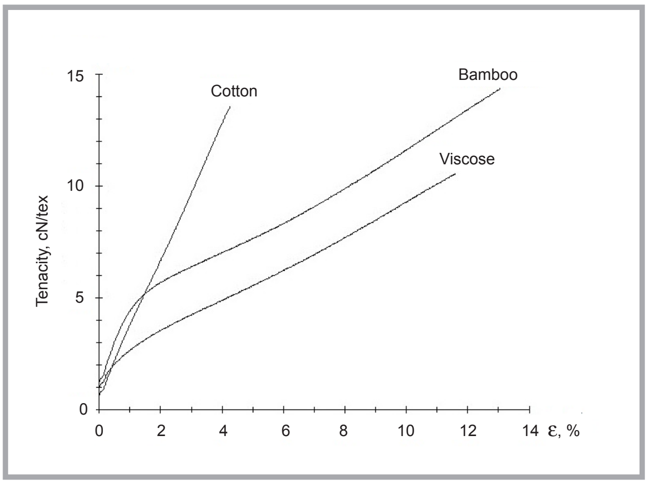

Figure 2. Stress-strain curves of cotton, man-made bamboo and viscose yarns.

in ***Table 2***. Static friction is related to the resistance force, which must be overcome at the beginning of sliding, when the solid body state changes from rest to movement. Dynamic friction starts with the solid's body movement, and is expressed as the force of the solid body's resistance to continuous movement. As can be seen in ***Table 2***, cotton and man-made bamboo yarns have approximately the same coefficients of static and dynamic friction, whereas the coefficients of friction of the viscose yarn are apparently lower. It means that the resistance of viscose yarn movement over the guide bars, thread guide and needle hook is lower than that of cotton and man-made bamboo yarns, whereas the resistance of bamboo yarn to the movement mentioned above is very close to that of cotton yarn, while the nature of man-made bamboo yarn is nearer viscose yarn. From the results presented in ***Figures 1.a*** and ***1.c,*** it can be seen that the loop length and course spacing of cotton and man-made bamboo knits have very close values.

In ***Figure 2*** and ***Table 3***, the stress-strain curves and tensile strength parameters of cotton, man-made bamboo and viscose yarns are presented. The character of each curve shows that the tensility and rigidity of these yarns are quite different. The results obtained show that the tensility of man-made bamboo yarn is similar to that of viscose yarn, whereas the strength of man-made bamboo yarn is closer to that of cotton yarn, although at significantly higher elasticity. However, the more important parameter for yarn behaviour during knitting is the initial modulus of elasticity, which specifies the behaviour of yarn in low stress intervals and can be obtained from the stress-strain curve. It is interesting that man-made bamboo yarn has an initial elasticity modulus value close to that of cotton yarn and twice greater than that of viscose yarn, the other man-made cellulose yarn. Therefore the resistance to sinking into the loop of man-made bamboo yarn is comparable to that of cotton yarn.

The loop shape factor enabled us to evaluate the fabrics knitted at different course and wale densities and to compare their properties, which depend on the loop length, porosity, tightness, etc. of the knits. The loop shape factor is a comparative quantity found as the ratio of course spacing and wale spacing and depends on the knitting pattern and raw material of yarns. The experimental results obtained showed that the number of yarns in the loop and raw material of the yarn influence the course and wale spacing as well as the dependence of the loop shape factor on the parameters mentioned, which is a logically expected result. Results presented in ***Figure 3.a*** demonstrate that the loop shape factor of man-made bamboo knits have very close values to those for cotton, whereas viscose knits (especially from yarns with a higher total linear density) have higher values of the loop shape factor. It is known that the optimal value of the loop shape factor for single jersey knits from cotton yarns is about 0.86 [18]. It is interesting that according to the results presented in ***Figure 3.a***, knits with an optimal loop shape factor value can be knitted from two cotton or man-made bamboo yarns with a 19.5 tex linear density and from three viscose yarns with a 19.5 tex linear density. This instance illustrates well the influence of the yarn's raw material on the structural properties of knits and demonstrates that regardless of the same cellulose nature of all yarns investigated, the behaviour of cotton, man-made bamboo and viscose yarns during knitting is different, giving a structure with different geometrical parameters. Naturally the physical properties of such knits should also be different.

In ***Figure 3.b***, the results of air permeability of the knits investigated, made from cotton, man-made bamboo and vis-

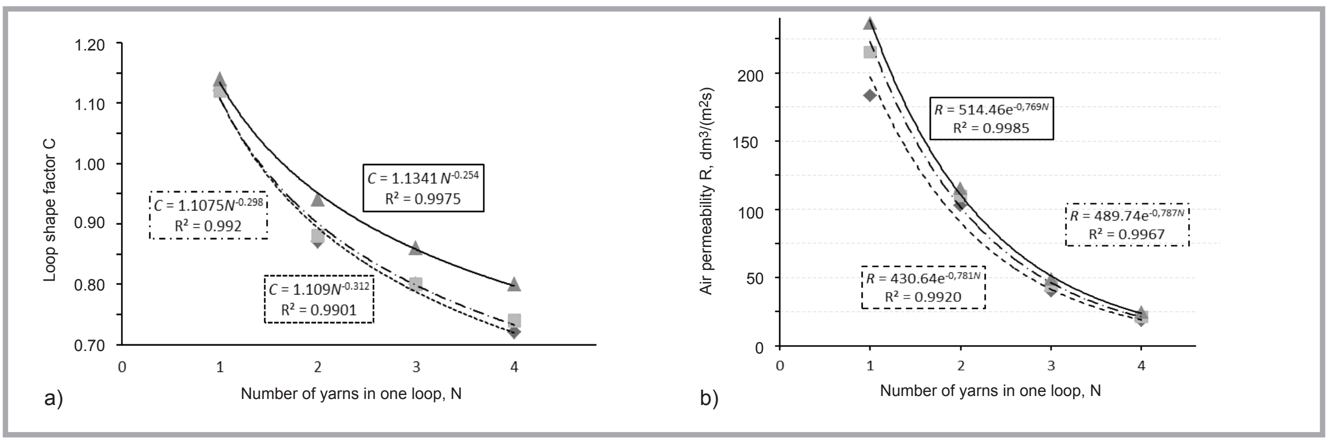

Figure 3. *Dependence of: a) loop shape factor and b) air permeability on the number of yarns in one loop and raw material of yarn;* ● *- Cotton,* ■ *- Bamboo, and* ▲ *- Viscose.*

cose yarns, are presented. As was mentioned before, this physical property was chosen because it is directly concerned with the structural properties and porosity of knits, i.e. the loop length. Whereas the linear density and twist of all yarns used was the same, just one property of yarns of different raw material could have an influence on the air permeability of knits – the hairiness, which was not clear for the yarns investigated. The results presented demonstrate that viscose knits have the highest air permeability and cotton knits – the lowest. These results were expected regarding the higher porosity of viscose knits (because of the longer loops in the knit). The air permeability of man-made bamboo knits has values closer to those of viscose knits than for cotton knits, despite the fact that the loop length in bamboo knits is very close to that of cotton knits. Taking this into account, probably the smoothness of the surface of man-made bamboo has an influence on air permeability, because man-made yarns normally have lower hairiness than cotton yarn.

Summarising the results obtained, it can be stated that predicting the physical properties of knits from new generation fibres (such as man-made bamboo fibres) without appropriate experiments is impossible. In this research work the behaviour of man-made bamboo yarns and knits was presented in comparison with other cellulose yarns, and it was found that man-made bamboo knits are sometimes similar to cotton knits and sometimes to viscose knits. The behaviour during the knitting of man-made bamboo yarn and the geometry of loops knitted from them are very similar to those of cotton and differ from other man-made cellulose yarn e.g. viscose. On the other hand, some physical properties, such as the air permeability of man-made bamboo knits are close to those of viscose but differ from those of cotton knits. It can be stated that comprehensive investigations of the mechanical and physical properties of knits from new kinds of yarns are essential.

As the experimental results obtained show, it is not correct to transfer the functional properties of yarns direct to the functional properties of knitted fabric. Furthermore, as is well known, the structure of knitted fabrics has a similar impact on many physical properties, such as the raw material. The raw material of yarn affects not only the functional properties (such as thermal conductivity, water absorption, etc.), but also the geometry of the loops.

Conclusions

It should be emphasised that the interesting observation presented in the following conclusions are related to an accepted set of preliminary selected conditions, and cannot be generalised without further investigations

- The structural parameters of knits from man-made bamboo yarns such as the loop length, course spacing, and loop shape factor are closer to those of cotton knits than to those of viscose ones. The influence of the raw material on the loop length of yarns is observable for knits with a looser structure, and that on wale spacing and the loop shape factor mentioned above is observable for knits with a tighter structure.
- The length and shape of knitted loops are influenced by the rigidity and frictional properties of yarns. The values of static and dynamic coefficients of friction and the initial elasticity modulus of man-made bamboo yarn are very close to those of cotton yarns (with the same linear density and twist factor) but differ from viscose, the other man-made yarn.
- The air permeability of man-made bamboo knits has values closer to viscose knits than to cotton ones, despite the fact that the structural parameters (such as loop length, course spacing and loop shape factor) of bamboo knits are very close to those of cotton knits.
- Despite the fact that all yarns of the knitted fabrics investigated have a cellulose nature, the behaviour of yarns during knitting differs. Therefore it is impossible to predict the physical properties of knits from man-made bamboo yarns in accordance with the widely investigated cotton or viscose knits without appropriate investigations.

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