Balakrshnan Senthil Kumar[1,*], Thangavelu Ramachandran[2]

[1] **NIFT-TEA Knitwear Fashion Institute,**
Tirupur-641 606, Tamil Nadu, India
* e-mail: bsenthilkumar_123@yahoo.co.in

[2] **Karpagam Institute of Technology,**
Coimbatore- 641105, Tamil Nadu, India

Influence of Knitting Process Parameters on the Thermal Comfort Properties of Eri Silk Knitted Fabrics

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Abstract
Eri silk, a wild silk variety available in the northeastern states of India, has better softness, tensile and thermal properties. The present study aimed to develop different knitted structures and investigate the influence of knitting process variables on the thermal comfort and wicking properties. Knitted single jersey and single pique fabric structures were produced with two sets of yarns – 25 tex and 14.32 tex with three levels of loop length. Thermal properties of the fabric were analysed using an Alambeta instrument, and the wicking ability was measured with an vertical wicking tester. Thermal comfort properties of eri silk were also compared with those of conventional mulberry silk, with the experiment result revealing that eri silk has better comfort values. A statistically significant correlation is found between knitting process parameters viz. the yarn count, loop length knitting structure and the thermal and wickability values of the fabrics.

Key words: *eri silk*, *mulberry silk*, *single jersey, single pique, thermal conductivity, thermal absorptivity, wicking.*

Introduction

India is the only country producing all four commercial varieties of silk, namely mulberry, tasar, eri, and muga**.** Eri silk, a wild silk variety, is produced from a domesticated multivoltine silkworm named Philosamia ricini, which feeds mainly on castor leaves. Eri sericulture is primarily cultivated in the north-eastern states of India by tribes. Eri silk cocoons are open-mouthed, which cannot be reeled like mulberry silk, which is spun into yarn in the worsted spinning system [1]. Since the silkworm is not killed during the production process, eri silk is denoted as "Ahimsa Silk". The spinning of eri cocoons was traditionally done by tribes on a Takli/spinning wheel, where spinners used Khar, an alkali produced by the burning of husk for degumming. Recently with the continual technological innovation initiatives of the Indian Silk Research Institutes the eri silk cocoon conversion process of degumming, opening and staple length cutting have become mechanised. Eri silk yarn which is produced in the worsted spinning system is suitable for high-speed weaving and knitting machines. Eri silk has better softness than other silk materials as well as better thermal insulating properties than wool and higher comfort than cotton [2, 3]. Fibre property values are given in ***Table 1***.

Eri silk fibres have more or less triangular a cross-sectional shape, with the presence of fewer striations and voids on the fibre surface. The higher specific heat capacity of 1.38 J/gK (Morton and Hearle [4]) is coupled with pores/ voids in the cross-section. Sen and Murugesh Babu [5] reported that the micro structure affects the density values of silk fibres. While analysing the chemical composition, it was found that degummed eri silk fibre contains about 20 different amino acids, in which the proportions of alanine and glycine are about 40% and 25% respectively, whereas the proportion of glycine is higher in mulberry silks. The acidic amino acids of aspartic and glutamic acid and the basic amino acids of arginine, histidine and lysine have higher proportions in eri silk fibroin [6, 7]. Utilisation of knitted fabrics for functional garments is emerging, as it provides better comfort, good extensibility, shape retention to the body and soft feel, as well as being of lightweight, with wrinkle resistance and ease of care. Knitted structures provide good thermal and moisture management properties for active applications [8]. Thermo-physiological comfort characteristics i.e. thermal conductivity, insulation and the sweat absorption rate are greatly influenced by the fibre type as well as yarn and fabric construction parameters [9-11]. Fabric surface characteristics such as roughness and hairiness also have an influence on the thermal properties. Rough fabric has a smaller contact surface and feels warmer, and fabric with more hairiness encapsulates more air, also giving warmness [12]. Oglakcioglu et al [13] studied the thermal comfort properties of basic single and double knit structures with cotton and polyester materials and reported that double knit structures of interlock and single rib fabrics have a higher thermal conductivity and thermal resistance value, and that single knit fabrics give a warmer feeling, with lower thermal ab-

Table 1. *Fibre properties.*

Fibre property	Eri silk	Mulberry silk
Density, g/cm^3	1.31	1.34
Fineness, dtex	3.33-4.44	2.22-3.33
Tenacity, cN/tex	27.43	37.17
Initial modulus, cN/tex	230.09	814.15
Elongation at break, %	22.00	19.00
Moisture regain, %	10.12	9.00

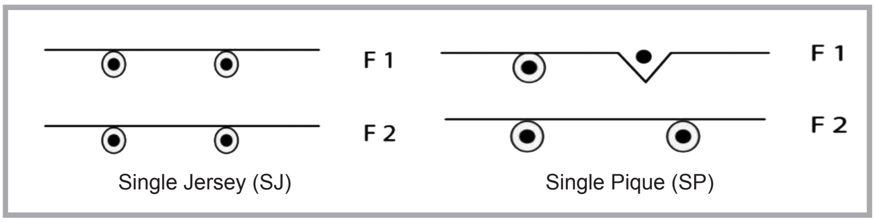

Figure 1. *Fabric structure – stitch diagram.*

sorption values. Suganthi et al [14] studied the comfort properties of bilayer knitted fabrics made out of tencel yarn on the outer layer and Micro polyester/acrylic yarn on the inner layer, and reported that fabrics with micro polyester have low thermal resistance when compared with other fabrics. The thermal comfort properties of plated knitted fabrics are suitable for warm conditions because of high thermal properties and have low permeability to the passage of air [15].The wicking property of textile is one of the effective indexes to determine moisture transmission and wearer comfort. Zhu et al [16] analysed the wicking behavior of cotton woven fabric and reported that the rate of wicking is higher at the beginning, and with increasing fabric weight a decrease in wicking was observed. Y Jhanji et al [17] analysed the influence of fabric structures, loop length and fabric physical characteristics on the wicking properties of knitted fabrics made out of 100% acrylic yarns. They reported that the knitted structure has a significant impact on the wicking height, that single knit structures have higher values than double knit structures, and that slack forms of all structures have higher transfer wicking ratios when compared with their tight structures. According to Nazir et al [18], slack knitted fabrics exhibit good air permeability but poor moisture management properties.

Various investigations have been made by researchers on the thermo-physiological comfort characteristics of knitted fabrics with different fibres, yarn types and fabric structures. Eri silk has unique thermal, physical and moisture management characteristics when compared with other commercial silk varieties [4, 5, 19]. The aim of this research was to study the influence of yarn count, loop length and fabric structure on the thermal comfort properties of eri silk knitted fabrics and also to investigate the thermal performance of eri silk compared with mulberry silk knitted fabrics. The results of this study ensure a new approach for the use of eri silk products for diversified end uses.

Table 2. *Eri silk yarn properties.*

Yarn linear density	25.00 tex, $2/80^s$ Nm	14.32 tex, $2/140^s$ Nm
Actual yarn count, tex	24.92	14.36
Count CV%	3.50%	3.40%
Twist value, TPM	531.50	502.20
Breaking force, gf	397	335
Elongation %	11.90	11.80
Tenacity, cN/tex	16.19	16.82
Unevenness U%	10.80	10.92
Thin/1000m, -50%	12	21
Thick/1000m, +50%	32	30
Neps/1000m, +200%	38	42
Hairiness index	4.22	4.60

Table 3. *Details of eri silk knitted fabric development.* ***Note:*** *Fabric development details* ***Table 2****.*

Sample code	Fabric structure	Yarn count, tex	loop length, mm
$SJ25_1$	Single jersey (SJ)	25.00	2.70
$SJ25_2$		25.00	3.00
$SJ25_3$		25.00	3.30
$SP25_1$	Single pique (SP)	25.00	2.70
$SP25_2$		25.00	3.00
$SP25_3$		25.00	3.30
$SJ14_1$	Single jersey (SJ)	14.32	2.40
$SJ14_2$		14.32	2.70
$SJ14_3$		14.32	3.00
$SP14_1$	Single pique (SP)	14.32	2.40
$SP14_2$		14.32	2.70
$SP14_3$		14.32	3.00

Materials & methods

100% worsted eri silk spun yarn was sourced from Uniworth textiles Raipur, India. The quality parameters of these yarns are given in ***Table 2***.

Fabric development

Eri silk knitted fabrics were developed on a single jersey knitting machine (Pailung), with a machine diameter of 24 inches, machine gauge of 24, a total number of needles of 1780, and number of feeders – 72. Twelve knitted fabrics were developed with two different counts: (25 tex ($2/80^s$ Nm) & 14.32 tex ($2/140^s$ Nm) and with knit structures such as single jersey (SJ) and single pique (SP), with three different loop lengths (***Table 3***, ***Figure 1***). Knitting was carried out with a constant yarn input tension of 3.5 cN/tex and knitting room humidity of around 60%.

To compare the thermal performance of eri silk with conventional silk, 100% Mulberry spun silk yarn of equivalent yarn linear density ($2/80^s$ Nm) was purchased from Banglore, India. Both single jersey and single pique were developed with the minimum loop length and same machine settings as for the eri silk sample development.

Physical properties

Fabric physical properties such as fabric weight per unit area (GSM) and thickness were measured according to the ASTM D3776 [20] and ASTM D1777-96 [21] standards. The air permeability of the samples was measured using a MESDAN Air-Tronic Air Permeability tester according to the ASTM D737-04/2008 standard. All sample tests were performed under the standard atmospheric conditions of 65% RH and 27 ± 2 °C. Five readings were taken for each of the samples.

Vertical wicking testing

The vertical wicking capabilities of the samples were determined by following the DIN 53924 standard in both the course and wale directions (***Figure 2***), as stated in literature [17]. The dimensions of the fabric specimen were 200 mm × 25 mm. The test was conducted in both the wale wise and course wise directions.

The specimen was suspended vertically, with its bottom end dipped in a reservoir of distilled water at a depth of 30 mm, as shown in ***Figure 2***. The wicking height was measured every minute for 10 min for direct evaluation of the fabric's wicking ability.

Thermal properties

Thermal properties of the fabrics were evaluated using an ALAMBETA instrument, developed by the Technical University in Liberec. The thermal conductivity (λ), thermal resistance (R), thermal absorptivity (b) and thickness of samples were determined in less than 3-5 mins. The test was carried out according to ISO EN 31092-1994, with the hot plate (maintained at 32 °C, which relates to human skin temperature) contacting the fabric sample at a pressure of 200 kPa. When the hot plate touched the fabric surface, the amount of heat flow from the hot surface to the next cold surface through the fabric was measured by heat flux sensors.

Results and discussion

Physical properties of knitted fabrics

The influence of knit process variables such as yarn count, loop length and fabric structure on the fabric weight and thickness is shown in ***Table 4***. The physical characteristics of eri silk knitted fabrics are in accordance with standard knit behaviors. Fabric weight (GSM) increased with a decreasing loop length or else with increasing yarn linear density. Single pique fabrics show higher weight than single jersey fabric, irrespective of yarn count and loop length. These results confirm the previous findings regarding the correlation of yarn count and loop length with the fabric weight by CD Kane, [11] and the fact that the knit-tuck stitch combination increases the weight, as stated by S. Uyanik et al [22].

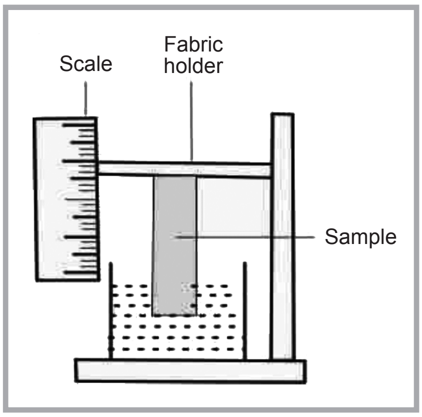

Figure 2. *Vertical wicking tester.*

Air permeability

The air permeability of fabrics is described as the rate of air transmission under predetermined air pressure, in a specified area, at a particular time. The air permeability of the fabrics is depicted in ***Table 4***, showing that the rate of air transmission increases gradually with an increasing loop length as well as from coarser to finer yarns. Also single pique fabric of knit-tuck combination stitches has higher air permeability than single

Table 4. *Eri silk knitted fabrics – physical and thermal properties.*

Sample code	Fabric areal density, GSM	Fabric thickness, mm	Air permeability, cm^3/cm^2/s	Thermal conductivity, (W/mK) × 10^{-3}	Thermal absorptivity, Ws$^{0.5}$/m^{2}K	Thermal resistance, (m^2 K/W) × 10^{-3}
SJ25$_1$	250	0.82	302.32	28.4	78.4	33.2
SJ25$_2$	220	0.78	327.02	25.4	76.3	31.5
SJ25$_3$	205	0.72	378.80	24.3	74.1	30.2
SP25$_1$	265	0.91	317.35	29.5	86.7	35.6
SP25$_2$	223	0.85	374.78	28.7	84.5	34.1
SP25$_3$	208	0.78	432.25	26.7	80.2	32.5
SJ14$_1$	140	0.78	493.30	24.3	67.5	30.4
SJ14$_2$	128	0.69	504.32	22.6	63.3	28.5
SJ14$_3$	114	0.64	544.37	21.7	60.2	27.1
SP14$_1$	156	0.82	502.30	27.5	76.4	33.2
SP14$_2$	135	0.75	535.40	26.3	73.1	31.5
SP14$_3$	121	0.72	582.40	25.5	70.3	30.2

Table 5. *ANOVA indicating the statistical significance for process parameters.*

Process parameter	Items	Air permeability	Thermal conductivity	Thermal absorptivity	Thermal resistance	Wale direction wicking	Coarse direction wicking
Loop length	df	2	2	2	2	2	2
	Fcrt	3.98	3.98	3.98	3.98	3.98	3.98
	Fact	4.22	45.70	47.96	723.00	0.13	0.18
	P value	0.048	0.021	0.02	0.001	0.89	0.84
Fabric type	df	2	2	2	2	2	2
	Fcrt	3.98	3.98	3.98	3.98	3.98	3.98
	Fact	4.35	139.84	288.42	1640.25	4.25	4.29
	P value	0.040	0.007	0.003	0.001	0.045	0.047
Yarn count	df	2	2	2	2	2	2
	Fcrt	3.98	3.982	3.98	3.98	3.98	3.98
	Fact	108.73	104.11	525.80	1640.25	16.17	19.16
	P value	0.000	0.009	0.002	0.001	0.002	0.001

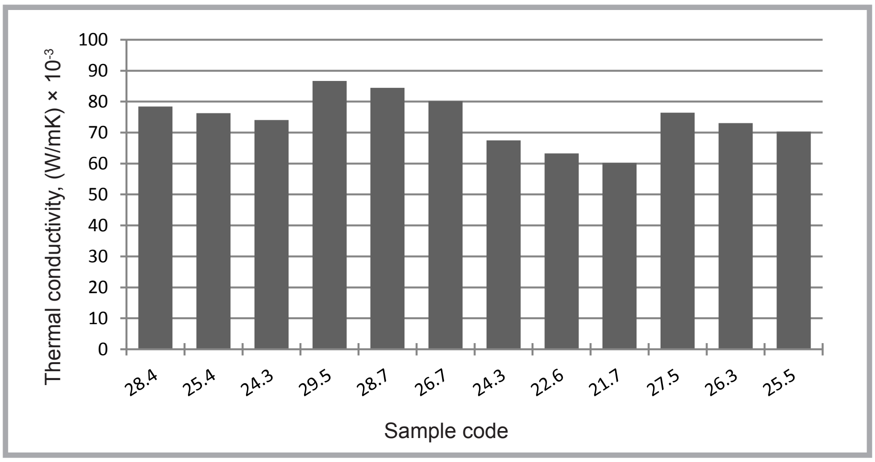

Figure 3. Thermal conductivity of eri silk knitted fabrics.

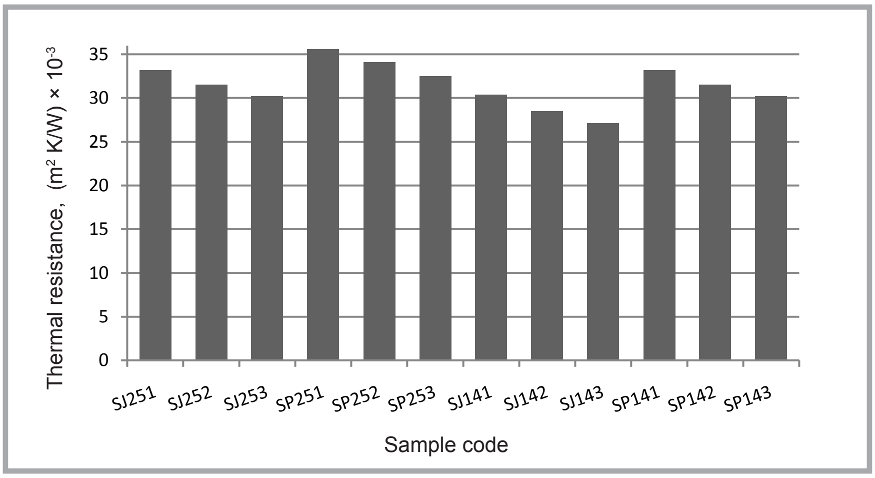

Figure 4. Thermal resistance of eri silk knitted fabrics.

jersey fabrics of plain stitches, because tuck stitches create pores in the fabric construction. ***Table 5*** shows ANOVA statistical analysis results at a 95% confidence level. Knitting process variables such as loop length, yarn count and fabric structure has significant correlation with fabric air permeability, as it is presented in ***Table 5***. $F_{act} > F_{crt}$ and p-values < 0.05.

Thermal conductivity

Thermal conductivity is an intrinsic property of a fabric which indicates its ability to conduct heat. It is the flux of heat divided by the temperature gradient. It is observed from ***Figure 3*** that the thermal conductivity of pique fabrics (average value range of Δλ28.43-26.43) is higher than for single-jersey fabrics (average value range of Δλ26.03-22.87), which might be due to the better air transmission properties of the pique structure. The situation was explained by Ramchandran et al [23] in his previous research, namely that the thermal conductivity values increase with an increase in the air permeability of knitted fabrics. It is also observed that the loop length and yarn count have a significant impact on the thermal conductivity properties. With an increasing loop length, the amount of fibre per unit area decreases and the amount of entrapped air increases inside the fabric structure due to the loosely bound loop configuration. The thermal conductivity of entrapped air is lower than for any textile fibres, which is attributed to low thermal conductivity at a larger loop length. The results confirm the previous findings by Jhanji et al [15]. Thermal conductivity decreases when the linear density is reduced within the same structure, which might be due to thicker fabrics, which is a result of coarser yarn, having fewer still air layers and more fibre channels for heat transmission, which provides higher thermal conductivity values. The fibre to air proportion increases with increased fabric thickness and weight of the fabrics. The highest thermal conductivity value was obtained for the SP25$_1$ fabric (single pique coarser yarn with smaller loop length), as shown in ***Table 4***, whereas the lowest was observed for the SJ14$_3$ fabric (single jersey finer yarn with larger loop length). Statistical analysis of the results shows that the loop length (Fact = 45.70 in comparison with Fcrt = 3.98), yarn count (Fact = 104.11 in comparison with Fcrt = 3.98) and fabric structure (Fact = 139.84 in comparison with Fcrt = 3.98) have significant influences on the thermal conduction properties of eri silk knitted fabrics with p values less than 0.05 at a 5% significance level.

Thermal resistance

Thermal resistance is the ratio of fabric thickness to fabric thermal conductivity. From ***Figure 4***, a higher thermal resistance value was observed with eri silk coarser yarn (ΔR~32.85) while comparing the finer (ΔR~30.15) yarns. This is due to increases in the thickness of fabric contributing a higher amount of air in the fabric interstices, which confirms the previous report by Stankovic B et al [24]. With eri knitted fabrics, if the yarn becomes finer or the loop length increases, the thermal resistance and thermal conductivity of fabrics also decrease proportionally. This contradiction is explained by Nida Oglakcioglu et al [13] in her research findings, namely that "Fabric thickness decreases when the yarn becomes finer due to a reduction in yarn diameter or when increases in loop length reduce the fabric weight. When the amount of fabric thickness decrease is more than the amount of thermal conductivity decrease, thermal resistance decreases as well, and hence thermal conductivity is also reduced". From ***Table 4***, the average thermal resistance value of single pique fabrics (ΔR for coarser yarn~34.07, finer~31.63) is observed to be higher than for the single jersey structure (ΔR for coarser yarn~31.60, finer~28.67), due to the increased thickness and weight of the fabrics. Statistical analysis of test results (***Table 5***) shows the significance of the interaction of yarn count [Fcr 3.98 < Fact 16.17 (p < 0.05)], loop length [Fcr 3.98 < Fact 1640.25 (p < 0.05)] and fabric structure [Fcr 3.98 < Fact 1640.25 (p < 0.05)] for thermal resistance at 95% confidence intervals.

Thermal absorptivity

Thermal absorptivity is the warm-cool characterisation or thermal feeling by human skin during instant contact with a fabric surface. Low absorptivity values indicate a warm feeling of fabric, while high absorptivity values indicate a cool feeling of fabric. The values in ***Table 4*** show that the fabrics knitted with coarser yarn and smaller loop length (SJ25$_1$ and SP40$_1$) have higher thermal absorption values than for fabric with finer yarn and larger loop length (SJ14$_3$ and SP14$_3$). This might be due to more contact points on the skin with the fabric with increased fabric weight. These results are similar to the earlier findings by Pac et al [12]. The thermal absorption trend of single pique fabrics (Δb for coarser yarn~83.80, finer~73.27) is better than for single fabrics (Δb for coarser yarn~76.27, finer~63.67), the value of which could be attributed to the higher bulkiness of the pique structure. Hence the eri silk knit pique structure with the highest absorptivity can be classified as cool feel fabric and single jersey as warm feel fabric. Statistical analysis (***Table 5***) proved that the thermal absorptivity of fabrics is influenced by the knitting process variables.

Vertical wicking ability analysis

Vertical wicking test results for the wale and course-wise directions are shown in ***Figure 2***, along with the apparatus. It is revealed from the ***Figure 6*** that eri silk knitted fabrics with coarser yarn possess better wicking properties than finer yarn. A higher number of fibres in coarse yarns led to higher capillarity and continuity of capillaries. The increased fabric thickness with coarser yarn also gives more space to hold water, as reported by Ozturk et al [25].

The wicking ability of single jersey fabrics is better than for single pique fabrics in both the course and wale directions. Liquid absorbency is closely related to pore size and distribution, and the porosity of pique fabric, due to tuck stitches in the course line, is attributed to poor wicking. The fabric of smaller loop length shows a better wicking tendency than the larger loop length, which is in accordance with the capillary principle mentioned by a previous researcher [26]. ANOVA statistical results indicate that process variables such as the knit structure and yarn count, except the loop length, have significant effects on the vertical wicking ability in both the wale and course directions at a 95% confidence level, while with the increased bulkiness of eri silk yarn, loop length has a minimal impact on vertical wickability. Furthermore in both knit structures longer wicking height was observed in the course-wise direction, with higher loop density in the

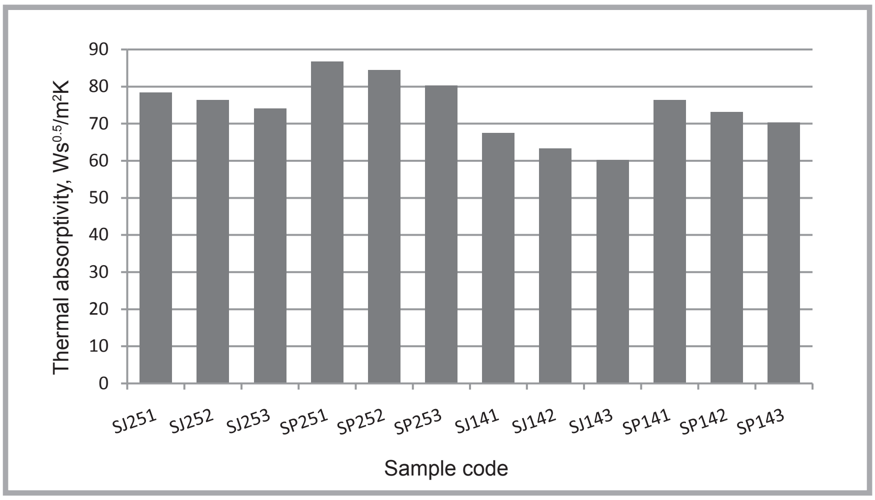

Figure 5. *Thermal absorptivity of eri silk knitted fabrics.*

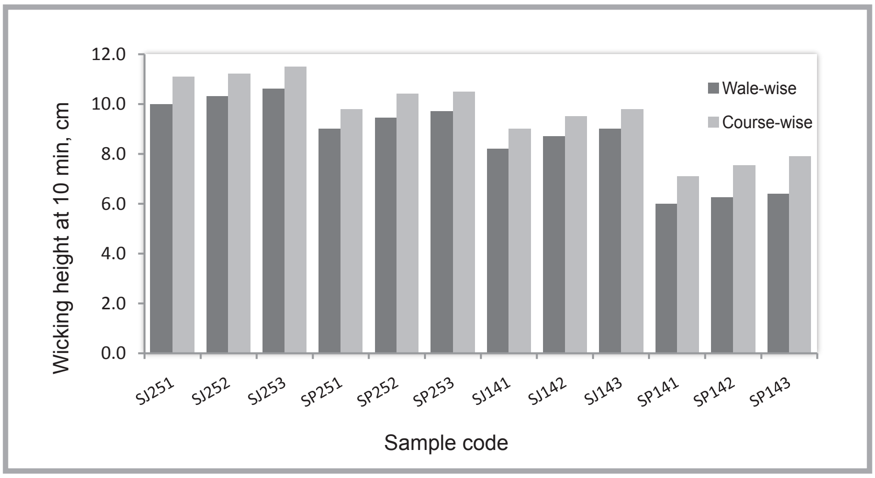

Figure 6. *Vertical wicking properties.*

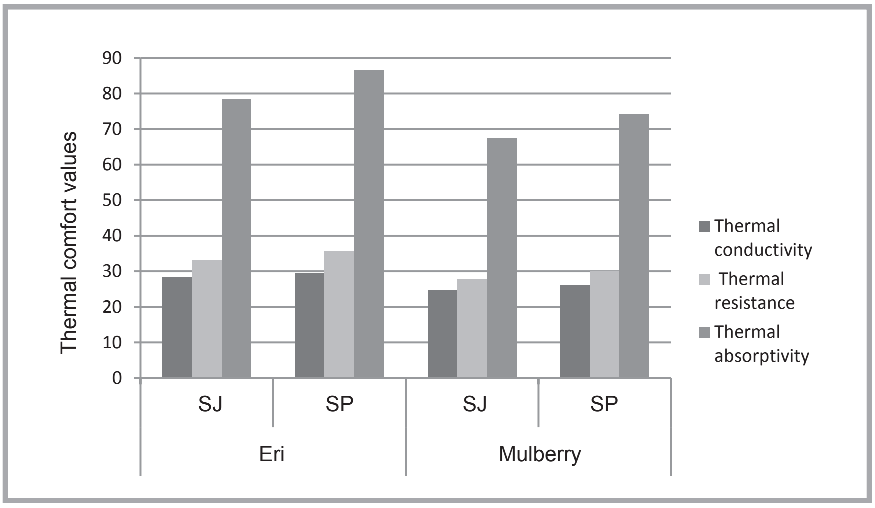

Figure 7. *Thermal properties of eri silk vs mulberry silk.*

Table 6. *Wicking height at 10 minute, cm – eri silk vs mulberry silk.*

Materials/directions	Eri silk		Mulberry silk	
	SJ	SP	SJ	SP
Wale-wise	10.0	9.0	9.2	8.1
Course-wise	11.1	9.7	9.7	9.0

course way direction contributing to this value. The paired sample "T" test P value of .000 indicates the presence of significance between both directions.

Thermal comfort performance of eri silk *Vs* mulberry silk

In order to investigate the influence of the fibre on fabric thermal properties, fabric weight was maintained, with a minimal difference with eri and mulberry fabric structures. From ***Figure** 7*, a lower thermal resistance value is observed for mulberry silk fabric as compared to that of eri silk knitted fabric. It is revealed from previous literature [1, 6] that to both the physical structure and chemical composition of fibres are attributed better thermal values. Among the silk varieties, Eri silk has a richer alanine content than mulberry silk, also possessing pores/voids on the fibre surface, where air becomes entrapped in the voids. Alanine is basically a carbon skelton contributing to the increased specific heat capacity of fibre, which, coupled with air entrapped in voids, results in better thermal insulation properties than for mulberry.

The thermal absorption values of eri silk knitted fabrics are about 16% higher than those of mulberry silk. These objective values indicate that eri silk gives a cool feel while mulberry silk offers a warm feel to the skin on initial contact with the fabric. The higher bulkiness and softness of eri silk fabric could be a possible reason for the better thermal absorptivity.

Vertical wicking ability of eri silk *Vs* mulberry silk

Table 6 demonstrates that eri silk knitted fabric has better wicking performance in both structures, which may due to the presence of a higher hydrophilic to hydrophobic amino acid ratio (9.06-9.85%) compared with mulberry silk (5.29-6.22), which confirms the earlier report by Babu et al [1].

The presence of amino acids in Eri silk contributes to better moisture regain properties, and the removal of the hygroscopic sericin layer from raw silk fibre during the degumming process leads to reduced moisture regain values with mulberry silk [7].

Conclusions

On the basis of the investigation carried out on eri silk knitted fabric, the following conclusions have been arrived at.

- Eri silk knitted fabrics have better thermal comfort properties and vertical wicking characteristics when compared with mulberry silk knitted fabrics.
- Loop length and yarn count have a significant influence on the dimensional properties of eri silk knitted fabrics. Fabric weight and thickness are decreased while increasing yarn linear density.
- The thermal conductivity of eri silk knitted single pique is better than for jersey fabrics; with the difference being higher regarding finer yarn counts. About a 15% value increment for 14.32 tex and 8.5% increment with 25 tex were observed. Loop length is inversely proportional to thermal conduction properties; coarser yarn has more (4.5% increase from a smaller to larger loop length) significance than finer yarn (2.6%).
- Thermal resistance values increased nearly 10% proportionately with the increasing yarn linear density in both eri silk knitted structures, as the coarser yarn contributed to increasing the thickness of the knitted fabric. Pique structures with a higher thickness and weight of fabrics than single jersey structures possess an ΔR value of coarser yarn of ~34.07, finer ~31.63 and ΔR value of coarser yarn of ~31.60, and finer~28.67, respectively.
- Eri silk knitted structures with coarser yarn and tighter stitch length gave higher thermal absorption, thereby providing cool feeling on initial skin contact.
- Vertical wicking has an influence on process variables such as the knit structure and yarn count, except the loop length, which have significant effects on the vertical wicking ability in both the wale and course directions at a 95% confidence level. The vertical wicking ability of single jersey structures shows better performance than pique structures, with more significance for a finer yarn count (27%) than a coarser yarn count (12.8%).
- From the findings above, it is concluded that eri silk single pique structures knitted with smaller loop lengths have better thermal performance, and optimum selection of right yarn count would enhance the wicking characteristics.
- The study also revealed that eri silk knitted fabric has good comfort properties, which confirms its suitability for light winter active applications. It is expected that knitted fabric produced from these yarns has good demand in the international market because eri silk fabric is produced by non-violent methods (without killing silk worm) and has better dimensional, thermal and wicking properties.

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LABORATORY OF ENVIRONMENTAL PROTECTION

The Laboratory works and specialises in three fundamental fields:

- **R&D activities:**
  - research works on new technology and techniques, particularly environmental protection;
  - evaluation and improvement of technology used in domestic mills;
  - development of new research and analytical methods;
- **research services** (measurements and analytical tests) in the field of environmental protection, especially monitoring the emission of pollutants;
- **seminar and training activity** concerning methods of instrumental analysis, especially the analysis of water and wastewater, chemicals used in paper production, and environmental protection in the paper-making industry.

Since 2004 Laboratory has had the accreditation of the Polish Centre for Accreditation No. AB 551, confirming that the Laboratory meets the requirements of Standard PN-EN ISO/IEC 17025:2005.

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Investigations in the field of environmental protection technology:

- Research and development of waste water treatment technology, the treatment technology and abatement of gaseous emissions, and the utilisation and reuse of solid waste,
- Monitoring the technological progress of environmentally friendly technology in paper-making and the best available techniques (BAT),
- Working out and adapting analytical methods for testing the content of pollutants and trace concentrations of toxic compounds in waste water, gaseous emissions, solid waste and products of the paper-making industry,
- Monitoring ecological legislation at a domestic and world level, particularly in the European Union.

A list of the analyses most frequently carried out:

- Global water & waste water pollution factors: COD, BOD, TOC, suspended solid (TSS), tot-N, tot-P
- Halogenoorganic compounds (AOX, TOX, TX, EOX, POX)
- Organic sulphur compounds (AOS, TS)
- Resin and chlororesin acids
- Saturated and unsaturated fatty acids
- Phenol and phenolic compounds (guaiacols, catechols, vanillin, veratrols)
- Tetrachlorophenol, Pentachlorophenol (PCP)
- Hexachlorocyclohexane (lindane)
- Aromatic and polyaromatic hydrocarbons
- Benzene, Hexachlorobenzene
- Phthalates
- Carbohydrates
- Glycols
- Polychloro-Biphenyls (PCB)
- Glyoxal
- Tin organic compounds

Contact:

INSTITUTE OF BIOPOLYMERS AND CHEMICAL FIBRES
ul. M. Skłodowskiej-Curie 19/27, 90-570 Łódź, Poland
Natalia Gutowska, Ph.D.
e-mail: nls@ibwch.lodz.pl, n.gutowska@ibwch.lodz.pl