NC STATE College of Textiles
JTATM
Journal of Textile and Apparel, Technology and Management

Volume 10, Issue 4, 2018

Understanding Morphology, next to Skin Comfort, and Change of Properties during Washing of Knitted Blends of Eri Silk

Rebecca Van Amber[1], Rangam Rajkhowa[1], Rechana Remadevi[1], Dilip Barooah[2], Maryam Naebe[1]
[1]Deakin University, Institute for Frontier Materials, Geelong, Australia
[2]Fabric Plus Ltd. Guwahati, India

ABSTRACT

Eri silk is a commercial variety of non-mulberry silk. It has competitive advantage of rearing and special characteristics compared to other silk varieties. However, only a few studies investigating properties of Eri silk fabrics have been published. The purpose of this work was to investigate the properties of knitted fabrics composed of Eri silk and blends with other animal protein fibers. Pure Eri silk yarn and blends with Merino wool/ cashmere and Suri alpaca were knitted into coarse and fine fabric structures. Fabrics mass per unit area, thickness, dimensional stability, handle and next to skin comfort properties were assessed before and after laundering for the first time. Most of the properties changed due to washing, with overall handle and comfort decreasing. The finding suggests that Eri silk fibers are best suited to blending with other protein fibers of similar fiber diameter and extra controls are required to ensure that the Eri fibers remain on the surface of the yarn, not migrate to the interior. The results suggest that properties of knitted Eri silk and Eri blend can be improved by appropriate blending of fibers of required fineness and changing the yarn manufacturing parameters.

Keywords: Eri silk, Merino wool, alpaca, knitted fabric, next to skin comfort, handle

Introduction

Eri silk is a commercially produced non-mulberry silk. The Eri silkworm is also a domesticated silkworm and is more resilient to cultivate than bombyx mori and fibers are finer than other non-mulberry silk fibers. Eri cannot be reeled due to the open-ended cocoon created by the silkworm and therefore only spun in to yarn using a staple fiber spinning approach. Eri like any other non-mulberry silk in particular is characterized by the elliptical cross section, which is expected to assist in providing a good drape. Traditionally Eri is used to prepare soft warm handspun and handwoven shawls and is also known for softness and thermal properties. Eri fiber softness, fineness and thermal properties are considered ideal for blending with other compatible fibers to produce high value soft, fine and warm fabrics. However, its blending behavior and the resulting properties of blended fabrics has not been systematically investigated. Understanding of these properties is important to determine ideal fiber specifications (i.e. fineness) of the blending components to achieve the desired outcomes.

The inclusion of the relatively finer Eri silk fibers blended with wool or alpaca may allow manufacturers to achieve Eri/ wool blend yarns and fabrics which are finer and more satisfactory to the consumer. Though fine Merino wool is known to be acceptable to use in next to skin garments, many consumers still believe that they have a wool allergy, and that wool is itchy to wear or causes prickle. To overcome the relatively poor next to skin properties of animal hair fibers including a relatively coarse wool, a blend with silk is often considered ideal as silk is known to be soft and has desirable next to skin properties. Wool blends with Mulberry silk are common, and researchers are beginning to understand the properties of woven suiting fabrics using different blends of Eri and wool (e.g. Das, Padaki, Jagannathan, Hubballi, and Naik (2017)). The inclusion of Eri silk fibers blended with wool or alpaca may allow manufacturers to achieve soft and fine wool blends more acceptable to the consumers. In such blends, wool is expected to contribute to Eri silk's lack of high elasticity while Eri adds softness and next to skin properties.

The aim of this work was to understand the properties of Eri blends in knitted fabrics. There is little published information on the product performance and next-to-skin properties of Eri blends and of those identified, only woven fabrics have been investigated. Eri fibers are traditionally used in woven fabrics but Eri's perceived softness make a good case for its application in knitted garments. However, one of the main problems with knitted silk fabrics is dimensional stability and changes to fabric properties as a result of washing and no reports investigating the effect of washing on comfort (prickle) and handle properties of Eri blends in knitted fabrics have been identified. Previous works have reported on the effect of water temperature on shrinkage and fiber damage (abrasion) to silk fabrics (Quaynor, Takahashi, & Nakajima, 1999, 2000; Van Amber, Niven, & Wilson, 2010). Though silk and silk blend fabrics can be machine washed, care must be taken to use low water temperature so that fabric damage observed as 'yarn hairiness' (Quaynor et al., 1999) or 'fiber fibrillation' (Van Amber et al., 2010) do not occur.

The current work sought to characterize and examine fabric properties of Eri and Eri-blend silk knitted fabrics before and after washing to determine anticipated consumer acceptability for properties such as next-to-skin comfort (prickle), handle, and dimensional stability. Another aim of this work was also to understand the potential problems of such blends so that necessary blend and process optimizations can be targeted as well as finishing treatments can be designed to meet the product performance needs.

Experimental details

Materials

Merino wool/ cashmere (80:20) blend sliver and Suri alpaca slivers were purchased from Cashmere Connections Pty Ltd. Australia. Eri sliver was provided by Fabric Plus ltd. India. Three yarns were produced; 100% Eri, 30:56:14 Eri/ Merino wool/ cashmere blend and 70:30 Eri/ alpaca blend. All yarns were 2/60 Nm and produced using a spun silk process at Fabric Plus Ltd. India. Single jersey knitted fabrics were produced on two different machines with coarse and fine structures. One (coarse structure) was 14 gauge flatbed hand knitting machine and 2 ends were fed at the same time, while the other (fine structure) was a 10 inch diameter circular knitting machine with 24 gauge. The courses/cm was 13.16 and wales/cm was 11.01.

Mass per unit area and fabric thickness measurements

Fabric mass per unit area (grams per square meter) and fabric thickness were determined at standard conditions (20±3 ℃ and 65±5 % relative humidity (RH)). Fabric specimens (N=3) were cut into 100 mm^2 circular samples using a circle cutter. Care was taken that the samples were cut from the middle part of the fabric roll to avoid uneven edges which might have influenced the results. A precision scale (± 0.1 mg), Metler Toledo Ltd., was used to determine the mass of each sample.

Fabric thickness was measured using Mitutoyo Corp thickness gauge with an applied pressure of 1 kPa. The results of three measurements (± 0.01 mm) on different areas of each sample were reported as the average thickness.

Mass per unit area and fabric thickness measurements were carried out before and after washing and the differences between values before and after washing were calculated. The test samples were then stored at the standard condition for over 20 hours prior to testing for their handle and comfort properties.

Morphology analysis

Yarns were embedded in TAAB TLV medium resin and then sectioned into 100–200 nm slices using an ultra-microtome (Leica EM UC6). Cross-sections were gold sputter coated (Bal-Tec Sputter Coater SCD 050) and then observed under a Zeiss Supra 55vp scanning electron microscope (SEM) at an accelerating voltage of 2 kV. The cross-sectional area of the fibres was determined using image analysis software (Image J software ver. 1.45 K). To measure the cross-sectional area of each SEM micrograph, a known scale bar (obtained from the SEM micrograph) was set using the software and a line manually drawn with a freehand tool to outline the fibre cross-sectional area.

Fiber diameter measurement

Mean fiber diameter (MFD, µm) and diameter distribution characteristics (coefficient of variation (CVD, %), standard deviation (s.d., %) and incidents of fibers at each diameter) of spun yarn of merino/ cashmere and alpaca fibers were also measured using the OFDA 2000 with 3000 counts for each sample (n=10 samples). From the fiber distribution data, the percentage of the fibers counted which exceeded 25 µm, 27 µm and 30 µm was determined.

Handle evaluation

Handle properties of the fabrics were tested using the Wool HandleMeter, according to the draft test method (IWTO. DTM-67) at standard conditions. The Wool HandleMeter uses the testing procedure of pushing a circular fabric sample through a nozzle, to define eight aspects of the force by displacement curve that are then used to characterize a set of seven bipolar handle attributes (Rough/Smooth, Hard/Soft, Loose/Tight, Light/Heavy, Clean/Hairy, Cool/Warm and Greasy/Dry) and Overall Handle. For testing, the circular fabric sample was loaded and centralised on top of the orifice plate. Then the mass plate (453 g) was automatically lowered onto the knitted fabric sample. Immediately after that a force rod pushed the fabric fully through the orifice. A displacement by force curve was obtained and the Wool HandleMeter algorithms converted the curve into numerical values for the seven primary handle attributes and Overall Handle. Fabric handle evaluation was carried out on fabrics before and after washing.

Comfort evaluation

Next to skin comfort of fabrics were evaluated using Wool ComfortMeter. This device has been developed to objectively assess the comfort properties, particularly the perception of garment induced prickle (McGregor et al., 2013; Ramsay, Fox, & Naylor, 2012). The discomfort in some garments has been shown to be caused by the mechanical stimulation of pain receptor nerve endings in the skin caused by protruding fibre ends applying a force to the skin greater than approximately 0.75 mN (Garnsworthy, Gully, Kenins, Mayfield, & Westerman, 1988). The Wool ComfortMeter uses a measurement wire mounted in a recording head, which scans the surface of the fabric, interacting with fibres protruding from the fabric surface. The results are sensitive to variations in the spatial density, length and diameter of the stiff fibre ends protruding from the fabric surface (Maryam Naebe, McGregor, Swan, & Tester, 2015).

Testing procedure using Wool ComfortMeter followed the established test method at standard conditions (International Wool Textile Organisation, 2014; M Naebe, Lutz, McGregor, Tester, & Wang, 2013). The back of the samples (next to skin side) was lightly steamed and fabrics were conditioned at the standard conditions for over 20 hours prior to testing on the Wool ComfortMeter. Fabric comfort evaluation was carried out on the back of the sample and five measurements were carried out on each fabric. Then the average of five values along their standard deviation (s.d.) was determined. Comfort evaluation was carried out before and after washing the fabrics.

Dimensional stability

Dimensional stability was determined using 20 cm × 20 cm specimens (n = 3 reps). "Coarse" knitted Eri/Alpaca blend were n=2 due to very limited fabric size. Fabrics were determined to be dimensionally stable after 6 wash cycles (Gore, Laing, Wilson, Carr, & Niven, 2006) while subjected to wash type 8A as described in ISO 6330, 2000 (E). Specimens were laundered according to BS EN ISO 6330, 2001 using an Electrolux Wascator FOM71 CLS. A wool specific detergent was used for all loads. After each wash cycle, specimens were dried on a rack in ambient conditions, and conditioned for at least 24 hours in the standard atmosphere (International Organization for Standardization, 2005) prior to measuring of physical properties. The average of three measurements of fabric width and length before and after washing was used to calculate length, width and area shrinkage.

Statistical analysis

Fabric handle and comfort data were analyzed using a univariate analysis of variance (ANOVA), and dimensional stability was analyzed using a repeated measures analysis of variance using IBM SPSS® Statistics 23. The significant differences between fabric type (n=3), fabric structure (n=2) and treatment (n=2) were determined using a *p* -value < 0.001. The interaction between factors (fabric type, structure, and treatment) was also tested.

Results and Discussion

Yarn cross sectional images showing the fiber distribution and cross sectional shape of the constituent fibers are presented in Figure1. Fiber diameters calculated from yarn cross section are shown in Table 1. Table 2. shows the details of mean fiber diameter (MFD) and percentage of the wool/ cashmere and alpaca fibers greater than 18 µm, 25 µm, 27 µm and 30 µm as determined by OFDA from slivers used in spinning.

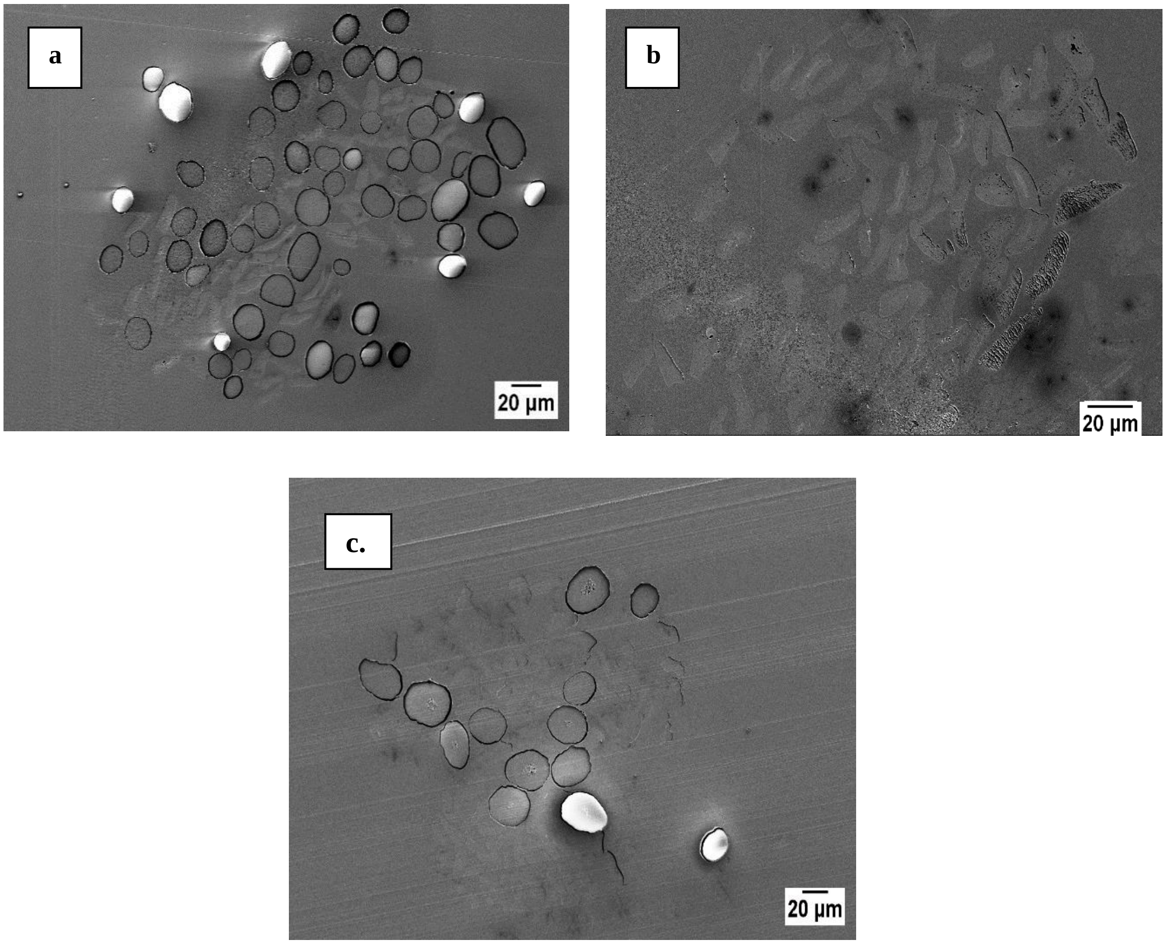

Figure 1. Yarn cross section of (a) Eri/ Wool/ Cashmere (30:56:14), (b) 100% Eri, (c) Eri/ Alpaca (70:30)

Table 1. Fiber cross sectional area (µm^2± s.d.) and calculated diameter from SEM images

Fiber	Cross sectional area (µm^2)	Equivalent diameter (µm)
Cashmere	128±21.5	12.7
Wool	434±65	23.5
Eri	125.5±30.7	12.6
Alpaca	617±67.5	28
Wool/Cashmere-blend	277 ± 146	18.7

Table 2. Details of mean fiber diameter (MFD) along with standard deviation (s.d.) and coefficient of variation (CV) as assessed by OFDA

Percentage of fibers sampled above the specified µm						
	Wool/ Cashmere (80:20) Sliver			100% Alpaca		
Fiber diameter	Mean (%)	s.d.	CV	Mean (%)	s.d.	CV
Average	18.7	4	21.9	27.5	7	25.5
>18	37.8	0	1.8	92.4	0	0.9
>25	3.9	0	3.3	56.0	0	3.0
>27	1.8	0	11.1	43.7	0	4.5
>30	0.9	0	24.6	32.4	2	6.1

Figure 1. shows that the cross section of Eri silk is flat and wedge shaped while wool and cashmere are more like circular and only difference lies in their size. All cashmere fibers are small with an average diameter of 12.7 micron while average wool fiber diameter was 23.5 µm (Table 1).

In OFDA measurement it was difficult to segregate wool and cashmere and mean fiber diameter of 80:20 wool/cashmere was found to be 18.7 µm (Table 2). As shown in Table 1., when the cross sectional area was measured combining wool and cashmere, the same 18.7 µm was found to be their average equivalent diameter. So the results from cross sectional measurement calculated from SEM images and that from OFDA agreed very well. However, due to the large size difference between wool and cashmere fiber diameters, when they were combined in OFDA measurement the standard deviation was very high. Cross sectional area of Eri fibers is very close to cashmere (Table 1). Since Eri fibers are wedge shaped, OFDA measurement was not taken for Eri to avoid large errors in calculation. OFDA measures only one axis of the cross section and there is a large difference between the major and minor axis of Eri fiber cross section.

The fibers of alpaca and Eri were not very uniformly distributed in the yarn cross section (Figure 1.c). They formed groups. This is likely from a large difference in the fiber diameter between the two fibers (Table 3). Among all fibers used in this study, alpaca fibers were the coarser fiber (MFD of 27.5 µm), with 43% of the fibers greater than 27 µm and 32 % of the fibers coarser than 30 µm. Coarser fibers (> about 30 µm) in the fiber diameter distribution have been associated with the neural basis and detection of fabric-evoked prickle (Garnsworthy *et al.,* 1988). The higher the percentage, the lower prickle responses. For wool/ cashmere with the MFD of 18.7, the percentage of the fibers coarser than 30 µm is about 1 %, much lower than that of alpaca (32%).

Fabric thickness measurements for coarse and fine knitted fabrics made of pure Eri silk, Eri/alpaca and Eri blended with wool and cashmere, before and after washing are summarized in Table 3. In general, all fabrics become thicker after washing, with higher changes shown in the coarser fabrics compared to the finer structure. While pure Eri fabrics and blended with wool/ cashmere exhibited the highest and identical changes in thickness, fabric silk blended with alpaca showed lower changes after washing.

Table 3. Mean fabric thickness and standard deviation (s.d.) of fine and coarse knitted fabrics before and after washing

	Thickness (mm) ± s.d		% Changes in thickness (mm) after washing
	Before washing	After washing	
Fabric samples	Coarse Knit		
Eri	1.07± 0.03	1.44± 0.04	34.1
Eri/Alpaca	1.05± 0.03	1.30± 0.05	23.7
Eri/ Wool/ Cashmere	1.07± 0.04	1.43± 0.01	33.9
	Fine knit		
Eri	0.75± 0.02	0.95± 0.02	26.5
Eri/Alpaca	0.77± 0.01	0.93± 0.03	20.7
Eri/ Wool/ Cashmere	0.74± 0.02	0.95± 0.01	26.7

Average of mass per unit area (GSM) before and after washing for all fabric samples used in this study, are in Table 4. The GSM of all fabrics increased after washing for both coarse and fine knit fabrics. Eri fabrics show the greatest changes after washing in both course and fine structure, followed by Eri/ wool/ cashmere and Eri/ alpaca fabrics.

Table 4. Average of mass per unit area (GSM± standard deviation) of coarse and fine knitted fabrics before and after washing

	GSM (g/m2)± s.d		% Changes in GSM after washing
	Before washing	After washing	
Fabric samples	Coarse Knit		
Eri	279.48± 12.61	402.84± 22.89	44.1
Eri/Alpaca	263.86± 6.60	292.57± 4.21	10.9
Eri/ Wool/ Cashmere	233.97± 8.14	303.66± 6.5	29.8
	Fine knit		
Eri	208.09± 1.24	278.82± 5.25	34.0
Eri/Alpaca	206.99± 3.20	237.06± 6.93	14.5
Eri/ Wool/ Cashmere	174.41± 3.8	232.53± 3.97	33.3

Table 5. shows the details of changes in fabrics dimensions after washing. Analysis of variance showed that none of the fabric parameters (fabric type or structure) significantly affected dimensional stability to washing ($p < 0.001$). All fabrics types both in fine and coarse structure had a high tendency to shrink and their dimensional changes are beyond what is deemed to be commercially acceptable. Fabrics were not washed or finished in any way, so this level of dimensional change is not unexpected. The fact that fabrics are becoming denser after washing is likely a direct result of the large percentage change in dimension – the largest of which was generally in the 100% Eri fabrics (Table 5). By adding alpaca or wool/ cashmere to the Eri, shrinkage reduced and reduction by adding wool/ cashmere is higher than alpaca. The results agree with the previous finding that showed alpaca fibers shrunk to a higher degree than wool fibers, and short and fine cashmere fibers have been found to have a lower shrinkage than wool fibers over a similar diameter range (Liu, *et al.,* 2007).

Table 5. Dimensional changes of coarse and fine knitted fabrics before and after washing

	Width (%± s.d.)	Length (%± s.d.)	Area (%)
	Before washing	After washing	
Fabric type	Coarse knit		
Eri	9.69± 0.006	24.61± 0.015	31.92
Eri/Alpaca	2.43± 0.011	18.03± 0.001	20.02
Eri/ Wool/ Cashmere	4.69± 0.009	13.60± 0.002	17.65
	Fine knit		
Eri	2.08± 0.005	25.19± 0.009	26.75
Eri/Alpaca	1.86± 0.009	20.31± 0.005	21.8
Eri/ Wool/ Cashmere	3.93± 0.014	15.24± 0.012	18.57

Table 6. shows the Overall Handle and seven primary handle attributes for each fabrics for both coarse and fine knit before and after washing. For each Wool HandleMeter parameter, the predicted value varies between 1 and 10, with 1 associated with the first term for the parameter and 10 being associated with the last term for the parameter. For example, for rough/ smooth, 1 is associated with an extremely rough fabric surface, and 10 with a very smooth fabric feel. Since the Wool HandleMeter was designed for the assessment of fine fabrics, and in this study, some of the fabric exceeded the upper limit of the device's capabilities (> 280 g/m^2 and 0.9 mm) after washing, the value of zero was assigned to the fabric handle parameter.

Table 6. The mean overall handle and seven primary handle attributes of coarse and fine knit structure before and after washing

	Before washing [a]			After washing [a]		
Wool HandleMeter Parameters	Eri	Eri/ Alpaca	Eri/ Wool/ Cashmere	Eri	Eri/ Alpaca	Eri/ Wool/ Cashmere
	Coarse Knit [b]					
Overall Handle	1.3	1.2	1.9	0	0.0	0.0
Rough/Smooth	0.7	1.0	1.4	0	0.0	0.0
Hard/Soft	2.7	1.9	3.5	0	0.4	0.7
Loose/Tight	6.9	8.2	6.2	10	8.9	7.8
Light/Heavy	8.5	9.3	7.5	10	10.0	10.0
Clean/Hairy	7.7	7.1	7.6	5.3	7.4	8.8
Cool/Warm	8.2	7.9	8.1	7.5	8.7	9.9
Greasy/Dry	10.0	9.9	9.8	10	10.0	10.0
	Fine Knit [b]					
Overall Handle	4.5	5.6	4.9	1.1	2.2	1.7
Rough/Smooth	3.4	3.8	3.5	1.6	1.6	0.9
Hard/Soft	5.2	5.5	5.8	1.5	2.8	3.2
Loose/Tight	5.6	5.1	4.8	9.2	7.6	6.6
Light/Heavy	5.0	4.9	4.0	9.4	7.5	7.1
Clean/Hairy	6.4	5.9	6.8	5.2	6.5	7.9
Cool/Warm	6.4	6.1	6.5	6.6	7.2	7.8
Greasy/Dry	8.2	7.4	8.2	9.7	9.5	10.0

[a] treatment (washing) was significant at the 0.001 level.

[b] structure was significant at the 0.001 level.

The structure (coarse vs fine) and treatment (washing) were generally the strongest factors on fabric handle, with the effect of fabric structure being slightly more important. Finer knit in all fabric types showed a better overall Handle, but it deteriorated due to washing. All washed fabrics felt rougher, harder, tighter and heavier compared to unwashed fabrics, whereas finer fabrics felt smoother, softer, looser and lighter than coarse structure. The Rough/ Smooth term is the tactile sensation associated with the surface topography of the fibers and fabric. A rough fabric will feel like it has obvious surface irregularities. The Hard/Soft term is a combined tactile feeling associated with the bending stiffness and lateral compression of the fabric. Loose/Tight is a sensation associated with the biaxial stretch and recovery of the fabric and is largely determined by fabric construction. Light/Heavy is the sensation of weight not necessarily the actual weight of the fabric. Combined results from Table 3, 4 and 6 show a thicker fabric feels heavier and a thinner fabric feels lighter. Washing resulted in fabrics feeling significantly heavier than unwashed fabrics.

Clean/Hairy is the sensation associated with the number and length of fibers on the surface of the fabric such that if it feels like there are lots of fibers it is hairy and if it feels that there are not many fibers on the surface, it is clean. Both coarse and fine Eri silk fabrics felt cleaner after washing, suggesting that washing may have removed some protruding fibers. However, Eri blends with alpaca and wool/ cashmere showed hairier surfaces after washing. A combination of the rougher feeling surface and tighter structure caused by washing might be the reason for the hairier sensation of these two fabric types.

The Cool/Warm sensation is the temperature sensation that occurs when the fabric first comes into contacts with the skin. Due to transient heat flow to or from the body surface, the sensory receptors of the human skin detect temperature changes that produce the thermal sensation of warmth or coolness (Rombaldoni, *et al.*, 2010). The thermal sensation is also related to the fabric surface contour and the surface area of contact (Barker et al., 1990). While all kind of fabrics felt warm, coarser fabrics show higher sensation of warmness compared to the finer structure. The higher thickness of coarse fabrics could also be responsible for increasing the air trapped in the fabric, which can be interpreted as a key factor for the change in the Cool/ Warm sensation of coarse fabrics compared to the finer structure. The Greasy/Dry sensation is the extent to which a fabric feels greasy or slippery. This sensation is usually caused by the addition of chemical softening agents. All fabrics felt very dry, and dry sensation enhanced after washing. This could be due to the fact that no softening detergent was used in this study. In addition, washing may have removed some waxes (spin finish) from the surface of the fabrics, which resulted in a drier handle.

Next to skin comfort of fabrics tested by Wool ComfortMeter are summarized in Table 7. Through analyses of extensive subjective wearer trial data, it was shown that the Wool ComfortMeter reading is strongly correlated with the average prickle rating assigned by wearers of the garments; the higher the Wool ComfortMeter value, the higher prickle rating. The relationship is such that a Wool ComfortMeter measurement of less than about 270 is associated with an average wearer response of no detection or barely detectable prickle. If some slight detection of average prickle response is acceptable Wool ComfortMeter values of up to ≈ 450 would be suitable (McGregor, *et al.*, 2013; Naebe, *et al.*, 2015). It was also shown that the critical fiber diameter for fabric-evoked prickle depends on the length of the protruding fibers (Naebe, *et al.*, 2015) such that fibers as fine as 10 µm can evoke prickle responses provided the length was short enough.

Most of the parameters investigated in this study significantly affected fabric comfort, with fabric type and fabric structure being the largest factors, and washing having less effect. However, the comfort of the different fabrics after washing changed depending on the type of fabric, with the Eri/ alpaca blend becoming more comfortable after washing when coarsely knitted, but less so when finely knitted.

As shown in Table 7, only fabric made of Eri silk can be accepted as a fabric comfortable next to skin; which is likely from the fineness and flat and wedged shaped cross section of Eri fibers. For this fabric type, the coarser structure showed better results before and after washing. While the same yarn was used for both structures, the coarser structure is thicker and has more open surface structure. Accordingly, more protruding fibers sit deep on the surface of the coarse structure compared to the finer structure. Therefore, fewer fibers protruding from the surface are available to be detected by Wool ComfortMeter.

Table 7. Mean Wool ComfortMeter (WCM± s.d.) value of coarse and fine knit structure before and after washing

	Before washing [b]	After washing [b]
	WCM± s.d.	WCM ± s.d.
Fabric type[a]	Coarse knit [c]	
Eri	248 ± 56	323± 51
Eri/Alpaca	1156± 56	1050± 50
Eri/ Wool/ Cashmere	901± 70	670± 25
	Fine knit [c]	
Eri	313± 79	501± 119
Eri/Alpaca	1029± 112	1333± 89
Eri/ Wool/ Cashmere	1142± 102	954± 110

[a] Fabric type was significant at the 0.001 level.

[b] treatment (washing) was not significant at the 0.001 level.

[c] structure was significant at the 0.001 level.

The blend of alpaca and Eri fiber was the least comfortable, which is understandable given the results of fiber diameter (Table 1 and 2). Alpaca contained a greater percentage of coarse fibers. Particularly when knitted into a coarser fabric structure, this resulted in fabrics which would not be considered comfortable in next-to-skin garments. As it can be seen from SEM images of yarn cross sections of the Eri/alpaca yarn (Figure 1.c), all of the Alpaca fibers were clustered and predominantly occupied the outside of the yarn, with the much finer Eri fibers migrating to the interior of the yarn’s structure, likely contributing to the poor comfort result of the Eri/alpaca blend despite having predominantly Eri fibers in the blend. Alpaca fibers may not be appropriate for blending with Eri fibers, and furthermore, during the spinning process, extra controls need to be in place to ensure the Eri fibers move to the surface of the yarn, not the interior.

It is not surprising that Eri/wool/cashmere blend is extremely uncomfortable next to skin, as assessed by the Wool ComfortMeter. Similar to the Eri/ alpaca blend, the majority of the wool/cashmere fibers are on the outside of the yarn (Figure 1 (a)). Although the average fiber diameter of wool/ cashmere used was 18.7 µm, it still contained predominantly coarse wool fibers of average 23.5 µm, which compromised fabric comfort. Due to the fineness of Eri fibers, more successful blends are likely to be those which include fine protein fibers (e.g. <16.5 µ Merino wool, or fine Cashmere).

The fabric handle and comfort properties depend heavily on yarn structure such as twist factor, hairiness, and uniformity. To capitalize the fineness of Eri and typical cross section of Eri to achieve much better results in the final fabric it is important to optimize the spinning processing parameters and produce a less hairy and uniform yarn. The flat cross section contributes to excellent drape and softness properties of woven fabrics as reported by Das, et al. (2017) if such yarn and fabric structural properties are optimized, it is expected that these same properties would be observed in knitted fabrics. It is also important to note the high shrinkage of Eri silk need to be controlled by optimizing twist in yarn, fabric constructions, blending components and appropriate finishing treatments to improve the dimensional stability of Eri silk.

Conclusions

This exploratory work on some of the properties of knitted Eri silk and Eri blend fabrics would suggest that yarn quality (hairiness and uniformity) must be improved to further improve the next to skin comfort properties of the blended fabrics. Current levels of shrinkage exceeded acceptable levels of ~5%, which causes the fabric to increase in thickness, mass per unit area, and a decrease in overall fabric handle and fabric comfort. Fabrics used in the current study would not be considered acceptable for next-to-skin garments, but with some appropriate modifications during manufacturing, Eri silk blend fabrics with improved properties can be produced, thus growing the Eri silk market. It is recommended that Eri is blended with fine protein fibers to ensure that the Eri fibers do not migrate to the centre of the yarn during spinning. Such modifications and appropriate design of blends will help to take the advantage of fineness of Eri silk fibers and more importantly, the wedge shaped cross section not seen in many other fibers in order to produce fabrics with good drape, comfort, and handle properties suitable for next-to-skin applications.

Acknowledgements

We acknowledge Australian Academy of Technology and Engineering for Prima Grant.

References

Barker, RL, Radhakrishnaiah, P, Woo, SS, Hatch, KL, Markee, NL, & Maibach, HI. (1990). In Vivo Cutaneous and Perceived Comfort Response to Fabric: Part II: Mechanical and Surface Related Comfort Property Determinations for Three Experimental Knit Fabrics'. *Textile Research Journal, 60*(8), 490-494.

Das, Brojeswari, Padaki, Naveen V., K, Jagannathan, Hubballi, B., & Naik, Subhas V. (2017). Studies on Handle Behaviour of Eri Silk / Wool Blended Fabrics Developed for Winter Wear Application. *Procedia Engineering, 200*, 53-60. doi: https://doi.org/10.1016/j.proeng.2017.07.009

Garnsworthy, RK, Gully, RL, Kenins, P, Mayfield, RJ, & Westerman, RA. (1988). Identification of the physical stimulus and the neural basis of fabric-evoked prickle. *Journal of neurophysiology, 59*(4), 1083-1097.

Gore, S.E., Laing, R.M., Wilson, C.A., Carr, D.J., & Niven, B.E. (2006). Standardizing a pre-treatment cleaning procedure and effects of application on apparel fabrics. *Textile Research Journal, 76*(6), 455-464.

International Organization for Standardization. (2005). ISO 139:2005 Textiles - Standard atmospheres for conditioning and testing. Geneva: International Organization for Standardization.

International Wool Textile Organisation. (2014). IWTO. DTM-66. Draft Test Method for the Skin Comfort of Finished Wool Fabrics and Garments. Brussels, Belgium: International Wool Textile Organisation.

McGregor, Bruce A, Naebe, Maryam, Stanton, John, Speijers, Jane, Beilby, John, Pieruzzini, Sara, & Tester, David. (2013). Relationship between wearer prickle response with fibre and garment properties and Wool ComfortMeter assessment. *Journal of The Textile Institute, 104*(6), 618-627.

Naebe, M, Lutz, V, McGregor, BA, Tester, D, & Wang, X. (2013). Predicting comfort properties of knitted fabrics by assessing yarns with the Wool ComfortMeter. *Journal of The Textile Institute, 104*(6), 628-633.

Naebe, Maryam, McGregor, Bruce A, Swan, Paul, & Tester, David. (2015). Associations between the physiological basis of fabric-evoked prickle, fiber and yarn characteristics and the Wool ComfortMeter value. *Textile Research Journal, 85*(11), 1122-1130.

Quaynor, Laticia, Takahashi, Masaoki, & Nakajima, Masaru. (1999). Dimensional changes in knitted silk and cotton fabrics with laundering. *Textile Research Journal, 69*(4), 285-291.

Quaynor, Laticia, Takahashi, Masaoki, & Nakajima, Masaru. (2000). Effects of laundering on the surface properties and dimensional stability of plain knitted fabrics. *Textile Research Journal, 70*(1), 28-35.

Ramsay, Donald J, Fox, David B, & Naylor, Geoffrey RS. (2012). An instrument for assessing fabric prickle propensity. *Textile Research Journal, 82*(5), 513-520.

Van Amber, Rebecca R, Niven, Brian E, & Wilson, Cheryl A. (2010). Effects of laundering and water temperature on the properties of silk and silk-blend knitted fabrics. Textile Research Journal, 80 (15), 1557-1568.

Wang, Henry, Mahar, Trevor J, & Postle, Ron. (2013). Instrumental evaluation of orthogonal tactile sensory dimensions for fine lightweight knitted fabrics. *Journal of the Textile Institute, 104*(6), 590-599.