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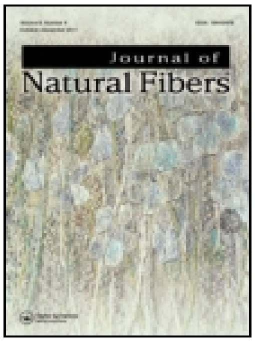


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# Evaluation of Comfort and Handle Behavior of Mulberry Silk Waste/Wool Blended Fabrics for End Use

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**ABSTRACT**

The present study investigates tactile, thermal, physiological comfort, and hand values of newly developed mulberry silk waste/wool blended fabrics for end use. Intimate blended fabrics $S_1$ (65s/35w, 2/33 × 33 tex) and $S_2$ (65s/35w, 2/25 × 25 tex) had higher resilience as well as warpwise extensibility, whereas union-blended fabrics $S_3$ (100w × 65s/35w, 2/33 × 33 tex) and $S_4$ (100w × 65s/35w, 2/25 × 25 tex) had high bending hysteresis, high tensile energy, lower coefficient of friction, and less geometric roughness. $S_1$, $S_2$, and $S_4$ fabrics exhibited higher transmission properties against air and moisture vapor whereas $S_3$ fabric showed superior thermal insulation properties. $S_1$ found significantly different ($p \leq .05$) from $S_2$ in terms of smoothness, uniformity, and aesthetic appearance. Total hand value of developed fabrics showed its suitablilty for women's light weight winter dress material and suitings, whereas union-blended fabrics were suitable for men's winter suitings. Stoles, mufflers, throws, and khes (bed covering) were the most suitable end uses in terms of intimate blended fabrics while shawls, lohis (gents shawl) mufflers, and khes were the most suitable end uses of union-blended fabrics.

**桑蚕丝/羊毛混纺织物终端用途的舒适性和手感性能评价**

本研究探讨新开发的桑蚕丝/羊毛混纺织物终端用途的触觉，热，生理舒适性和手感性能值。精密混纺织物S1（65s / 35W， 2 / 33×33 tex）和S2（65s / 35W，2 / 25×25 tex）有较高的韧性以及经向延伸性，而交织混纺织物S3（100W×65s / 35W，2 / 33×33 tex）和S4（100W×65s / 35W，2 / 25×25 tex）具有较高的抗弯滞后，高15抗张能量，摩擦系数较低，较少几何粗糙度。S1，S2和S4的织物表现出对空气和湿气更高的传输特性，而S3织物表现出优异的热绝缘性能。S1与S2在光滑，均匀性和美观方面发现显著差异（p≤.05）。手感性能值20的开发面料适宜女性轻质冬季服装面料和西装面料，而交织混纺织物适合秋冬男士西装面料。精密混纺织物最适合的最终用途是用在披肩，围巾，和印度粗斜纹布（床罩），同时交织混纺织物最合适的最终用途是用在披肩，罗溪丝（绅士披肩），围巾和印度粗斜纹布。

**KEYWORDS**
KES-FB; physiological comfort; silk/wool blends; tactile comfort; thermal comfort; total hand value; winter dress material

**关键词**
KES-FB；生理舒适；蚕丝/羊毛混纺；触觉舒适；热舒适；总手感性能值；冬季服装材料

## Introduction

With the trend of fashion toward natural, comfortable yet elegant fabrics, mulberry silk reeling waste/wool-blended fabrics were developed. Comfort and handle behavior of fabric is one of the most important aspects when designing the end uses of fabrics as these are the critical factor for consumer's purchasing decisions. Wool and wool: silk blends provide very good transmission against water vapor and air. (Behra and Mishra 2007). Total hand value of winter suitings increased with the

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increase in wool content and a good winter suiting possessed low surface friction, low variability in surface roughness, low bending and shear stiffness (Datta and Patel 1995). Contact interfacial area between skin and fabric is small for rough fabrics and more air is entrapped on a hairier fabric surface, so these fabrics give a warmer feeling (Pac et al. 2001). Despite the researches regarding tactile and thermal comfort, there is no research regarding handle and comfort properties of mulberry silk waste/wool blends had done. For this purpose, the low stress mechanical and surface properties of developed mulberry silk waste/wool intimate and union-blended fabrics had studied to determine the total hand value (THV) by Kawabata Evaluation System for Fabrics (KES-FB). Thermal comfort properties viz. thermal insulation, air and moisture vapor transmission properties are studied. In addition to it, physiological comfort properties of mulberry silk waste/wool blended fabrics are also studied which is depending upon the individual's perception and fiber/yarn composition.

## Materials and methods

### Fiber characteristics

Multivoltine mulberry silk reeling waste (hank) was degummed subsequently after knowing the sericin content. Degumming was carried out by boiling the silk hanks in soap solution under the following conditions:

Soap—6 g/L, Sodium carbonate—1 g/L, Temperature—90°C, Time—90 minutes,
M: L Ratio—1:40

After degumming, the fiberes were washed in soft water and dried at room temperature for 48 hours (Kumar et al. 2001). Mulberry silk waste fiber with linear density 1.2 denier, cut length 55.2 mm, and excellent whiteness index (100.8) found appropriate for blending with Australian merino wool tops exhibiting linear density 6.2 denier, length 55.3 mm, and outstanding moisture regain properties (12.4%) (Table 1). The higher tenacity of mulberry silk waste fibers 3.5 g/denier with high elongation (34.4) and lower modulus properties of Australian merino wool fibers were suitable for blending with each other to incorporate better appearance, texture, warmth, comfort, and strength in a intimate/union-blended fabric (Verma and Grewal 2011).

### Blending and spinning of fibers

Mulberry silk waste fiber was cut into the staple length of 55.2 mm which was compatible with the length of wool fibers and opened thoroughly by hand. Both the silk and wool fibers were hand fed separately into carding machine and the sliver was formed while passing the material through carded frame three times.

The blending of silk and wool slivers were done at gillbox (drawframe) stage in different ratios, that is, 100: 0, 65: 35, 50: 50, 35: 65, and 0: 100, passed three times each having 3.5 to 5 draft from it. Further drawing was done at the drawframe by giving four passages to the sliver keeping the draft of

**Table 1.** Fiber characteristics.

| | | Characteristics | | | | | |
|---|---|---|---|---|---|---|---|
| Fiber | Diameter (µm) | Linier density (Denier) | Length (mm) | Tenacity (gm/denier) | Elongation at break (%) | Initial modulus (gm/denier) (2% extension) | Whiteness index |
| Mulberry silk waste | 12.06 | 1.21 | 55.21 | 3.53 | 11.79 | 76.98 | 100.80 |
| CV% | (35) | (19.6) | – | (22) | (40) | | – |
| Australian Merino Wool | 24.21 | 6.19 | 55.26 | 1.34 | 34.44 | 9.29 | 85.33 |
| CV% | (27) | (21.2) | – | (26) | (38) | | – |

CV (%) = Percent coefficient of variation.

**Table 2.** Yarn characteristics of optimum-blended yarn.

| Linier density tex | Twists (per m) | U% |
|---|---|---|
| 33 | 633 | 22.01 |
| 25 | 796 | 23.50 |

7–8 with the spindle speed of 800 rpm. Drawn sliver samples of various proportions were passed on to the ring frame each given 15–16 drafts and spindle speed was maintained at 4200 rpm and finally spun into yarns with linear densities 33 tex and 25 tex (Table 2).

### *Analysis of optimum blended yarns*

Optimum ratio of blend for the fabric development were analyzed on the basis of strength, hairiness, and percent unevenness. Intimate as well as union-blended fabrics were prepared on a handloom subsequent to the assessment of optimum-blended yarns of both the counts.



### *Development of handloom woven fabrics and its constructional characteristics*

One set of fabric samples, each using intimate-blended yarns with linear density 33 tex ($S_1$) and 25 tex ($S_2$), was prepared on handloom in optimized proportion (65 percent silk: 35 percent wool) while another ($S_3$) and ($S_4$) of union-blended fabrics was prepared by taking 100% wool in warp direction and the blended yarn in the weft direction. Straight drafting system was adopted to produce four different sets of fabrics in twill weave. Yarns of linear density 2/33 tex and 2/25 tex (changed to S twist) were used as the warp, whereas yarn linear densities of 1/33 tex and 1/25 tex (z twist) were used in the weft.

The constructional properties viz. reed width, denting order, weave, cloth width were kept constant for all the fabrics whereas as thread density, mass, thickness, and cloth cover of the developed fabrics were varied (Table 3).

### *Assesment of fabric's tactile comfort*

Low stress mechanical and surface properties have been studied objectively by Kawabata Evaluation System for fabric (KES—FB) to determine Total hand value (THV) in order to observe tactile comfort (Kawabata and Niwa 1975).

**Table 3.** Constructional parameters of the blended and union fabrics.

| Constructional parameters | | Blended fabrics | | Union fabrics | |
|---|---|---|---|---|---|
| Fabric Code | | $S_1$ | $S_2$ | $S_3$ | $S_4$ |
| Fiber content | (Warp) | 65% silk:35% wool | | 100% wool | |
| | (Weft) | 65% silk:35% wool | | 65% silk:35% wool | |
| Yarn linier density (tex) | (Warp) | 2/33 | 2/25 | 2/33 | 2/25 |
| | (Weft) | 33 | 25 | 33 | 25 |
| Reed width (m) | | 1.32 | 1.32 | 1.32 | 1.32 |
| Denting order | | 2 ends/dent | 2 ends/dent | 2 ends/dent | 2 ends/dent |
| Weave | | Twill | Twill | Twill | Twill |
| Cloth width (m) | | 1.12 | 1.12 | 1.12 | 1.12 |
| Thread density (thr $cm^{-1}$) | (Warp) | 13 | 14 | 18 | 21 |
| | (Weft) | 12 | 13 | 14 | 17 |
| Fabric mass ($g/m^2$) | | 125.54 | 119.52 | 179.30 | 151.25 |
| Fabric thickness (mm) | | 0.30 | 0.28 | 0.45 | 0.32 |
| Cloth cover (kc) | | 15.14 | 14.50 | 18.70 | 19.10 |
| Warp cover factor (k1) | | 10.75 | 10.18 | 14.78 | 15.12 |
| Weft cover factor (k2) | | 7.12 | 6.78 | 8.31 | 8.64 |

### Assessment of fabric's thermal comfort

Thermal comfort is related to fabric's transmission behavior viz. air permeability, moisture vapor resistance and thermal insulation. Air permeability tests were conducted on prolific air permeability tester by test method IS: 11056-84. Ten specimens were taken for testing with exposed area of 10 $cm^2$ under a pressure head of 10 mm of water column. Thermal insulation was determined by using KES FB (Thermolobo II). The dry contact method with an air velocity of 30 m/s was used for the measurement of thermal insulation. The moisture vapor resistance was measured through evaporation cup method as per BS 7209. The moisture vapor resistance was calculated in gms of water passing through square meter of fabric in 24 hrs.

### Assessment of fabric's physiological comfort

End use derived from physiological comfort was determined by analysing the effect of fiber/yarn composition and structure on comfort behavior as well as subjective evaluation through the panel of judges.

### Statistical analysis

Anova was implied on the analysis of optimum ratio of blend for fabric development. Mann–Whiteny *U* test and weighted mean scores were applied for analyzing the physiological comfort characteristics of the fabrics.

## Results and discussion

### Analysis of yarn properties

The yarns were analyzed in terms of strength, hairiness, and evenness properties. The single yarn strength in 65s/35w blend showed the maximum value followed by 50s/50w blend in terms of 33 tex yarn count (Table 4). The strength for 100% silk was significantly increased ($p \leq .05$) on mixing 35% wool content. This may be due to the improvement in regularity of fiber denier. Increasing the proportion of wool fiber in subsequent proportions led to reduction in strength. Statistically, the differences among 100% silk, 65s/35w: 50s/50w were significant ($p \leq .05$). Yarn strength of 25 tex linear density was highest in case of 100% mulberry silk waste followed by 65s/35w blend. Hairiness was slightly more in the two pure yarns when yarns with linear densitiy 33 tex was analyzed (Table 4). Blending of both the fibers resulted in reduced hairiness (–) of pure yarns. Hairiness decreases with lesser yarn densities. In case of silk blends with linear density 25 tex hairiness was

**Table 4.** Optimization of yarn properties.

| | Properties | | | | | |
|---|---|---|---|---|---|---|
| | Tensile strength (gf) | | Hairiness (–)/m | | U% | |
| Yarn | 33 tex | 25 tex | 33 tex | 25 tex | 33 tex | 25 tex |
| 100% Silk | 209.15* | 208.85 | 7.62 | 7.32 | 27.92 | 28.28 |
| CV% | (34.92) | (26.61) | (3.10) | (1.76) | (1.23) | (5.08) |
| 65% s: 35% w | 280.05* | 164.22* | 7.21* | 7.08* | 24.01* | 24.55* |
| CV% | (12.60) | (22.47) | (2.0) | (2.60) | (1.22) | (2.38) |
| 50% s: 50% w | 224.02* | 82.58* | 7.44* | 7.24 | 23.54 | 24.04 |
| CV% | (23.46) | (4.68) | (0.79) | (0.74) | (1.07) | (13.18) |
| 35% s: 65% w | 201.70 | 60.57 | 7.45 | 7.10 | 21.60* | 23.04 |
| CV% | (15.93) | (4.69) | (0.72) | (1.07) | (0.79) | (0.76) |
| 100% wool | 121.97* | 43.35 | 7.86* | 7.00 | 19.34* | 20.98* |
| CV% | (21.80) | (9.90) | (2.80) | (3.50) | (2.1)) | (5.59) |
| CD | 42.47 | 29.33 | 0.21 | 0.20 | 0.49 | 1.16 |

*Significant at 5% level of significance, CD = Critical difference. CV (%) = Percent coefficient of variation.

found more as compared to pure wool due to irregular and protruding nature of silk waste fibers. Pure silk waste exhibited maximum unevenness percent due to the irregular denier of silk fiber/yarn. The percentage of unevenness decreased with an increase in wool content in yarn. When 35% wool was mixed with silk, the unevenness percentage decreased significantly ($p \le .05$) in both 33 and 25 tex yarns. Further, decrease in unevenness was observed as per the content of wool was increased in the yarn (Table 4). According to Tyagi (2004) the yarn unevenness with higher silk content is due to high twists that add higher crimp to the yarn, which gives a wavy effect owing to the mechanical hindrance resulting in a higher Uster value.

Therefore, The 65s:35w blended yarn for both the linear densities 33 tex and 25 tex was taken as the optimum blend due to its higher strength, lesser hairiness, and significantly improved ($p \le .05$) evenness as compared to pure silk.

## Evaluation of tactile comfort

### Evaluation of tactile comfort (low stress mechanical and surface properties) of intimate and union blended fabrics

Data furnished in Table 5 shows the low stress mechanical and surface properties of intimate and union-blended fabrics.

*Tensile properties.* Weftwise extensibility of the handloom fabrics was found to be higher, among all the fabrics in comparison to warp, due to the single ply weft which needs less force to extend sample $S_1$ showed maximum extensibility in the weft direction, whereas in warp direction $S_3$ showed highest extensibility. Warp yarns of union blended fabrics, showed a high extensibility due to wool's low initial modulus and crimped configuration. Higher value of EM provides wearing comfort but creates problem during stitching and steam pressing (Nayak et al. 2009).

The linearity of tensile property (LT) indicative of the wearing comfort of a fabric showed that the warpwise tensile linearity was highest among $S_1$ and $S_2$. The lower LT value of union blended fabrics was due to pure wool yarn in warp direction. However, $S_3$ fabric was the highest linearity in weft direction.

**Table 5.** Evaluation of low-stress mechanical and surface properties of intimate- and union-blended fabrics.

| | | $S_1$ | | $S_2$ | | $S_3$ | | $S_4$ | |
|---|---|---|---|---|---|---|---|---|---|
| Properties | | Weftwise | Warpwise | Weftwise | Warpwise | Weftwise | Warpwise | Weftwise | Warpwise |
| Tensile properties | EM (%) | 6.66 | 17.03 | 5.59 | 15.30 | 7.37 | 9.59 | 6.90 | 11.41 |
| | LT [–] | 0.79 | 0.44 | 0.69 | 0.43 | 0.61 | 0.59 | 0.63 | 0.53 |
| | RT (%) | 13.82 | 18.45 | 9.69 | 17.00 | 11.30 | 14.16 | 11.00 | 27.27 |
| | WT (g.cm/cm$^2$) | 33.12 | 31.66 | 29.69 | 28.17 | 47.33 | 34.27 | 43.08 | 29.76 |
| Bending properties | B [g/cm$^2$] | 0.05 | 0.03 | 0.04 | 0.02 | 0.15 | 0.04 | 0.15 | 0.02 |
| | 2HB[g.cm/cm] | 0.03 | 0.01 | 0.02 | 0.01 | 0.06 | 0.02 | 0.05 | 0.01 |
| Shear properties | G [g/cm.deg] | 0.27 | 0.23 | 0.24 | 0.23 | 0.42 | 0.44 | 0.32 | 0.36 |
| | 2HG[g/cm] | 0.33 | 0.26 | 0.30 | 0.21 | 0.64 | 0.68 | 0.35 | 0.55 |
| | 2HG5[g/cm] | 0.47 | 0.39 | 0.45 | 0.35 | 0.88 | 0.93 | 0.55 | 0.56 |
| | MIU[–] | 0.20 | 0.20 | 0.21 | 0.20 | 0.18 | 0.21 | 0.10 | 0.11 |
| Surface properties | MMD[–] | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 1.72 |
| | SMD[micron] | 4.22 | 4.54 | 4.38 | 4.78 | 4.00 | 3.94 | 3.67 | 4.25 |
| | LC[–] | 0.35 | | 0.33 | | 0.34 | | 0.32 | |
| | RC[%] | 66.30 | | 64.60 | | 56.98 | | 60.98 | |
| Compression properties | WC[g.cm/cm$^2$] | 0.41 | | 0.41 | | 0.42 | | 0.39 | |
| | $T_0$[mm] | 0.92 | | 0.91 | | 1.17 | | 0.98 | |
| | $T_m$[mm] | 0.45 | | 0.41 | | 0.63 | | 0.49 | |
| Weight | W[mg/cm$^2$] | 12.75 | | 11.85 | | 17.87 | | 14.82 | |

$S_1$ = Intimate-blended fabric made from 65s/35w, 2/33 × 33 tex yarn.
$S_2$ = Intimate-blended fabric made from 65s/35w, 2/25 × 25 tex yarn.
$S_3$ = Union-blended fabric made from 100w × 65s/35w, 2/33 × 33 tex yarn.
$S_4$ = Union-blended fabric made from 100w × 65s/35w, 2/25 × 25 tex yarn.

Weftwise tensile resilience (RT) of all the fabrics were higher in comparison to warpwise tensile resilience. $S_4$ fabric showed the highest RT value. Warpwise tensile resilience of $S_1$ was the highest followed by $S_3$, least being in $S_2$.

The toughness of a fabric reflected in the mobility of a garment under deformation, is indicated by the tensile energy. A higher tensile energy was found in the warp direction among all the fabrics. It was the highest in $S_3$ exhibiting maximum weight and thickness followed by $S_4$ and $S_2$ had the least value.

***Bending properties.*** Bending rigidity (B) of a fabric depends upon the bending rigidity of the threads and mobility of warp and weft threads within the fabric. Warpwise bending rigidity was higher than weftwise in all the fabrics, union-blended fabrics showed the higher warpwise bending rigidity in comparison to blended fabrics $S_1$ and $S_2$. For both the intimate and union-blended fabrics with yarns, linear density 33 tex showed high bending rigidity as compared to fabrics developed from fine yarn counts. This implied that mobility of warp and weft yarn was more in the low weight fabrics made from finer counts.

2HB represents the hysteresis of bending moment that is a measure of recovery from bending deformation. Warpwise hysteresis among all the fabrics was more as compared to weftwise due to higher end density as compared to pick density. Bending hysteresis of union blended fabrics was more than that to intimate blended fabrics in warp direction and $S_3$ showed the highest hysteresis. It was followed by $S_3$, $S_1$, and $S_2$ (least hysteresis). A similar trend was observed in weftwise direction also but there was very less variation between the fabrics.

***Shear properties.*** Shear rigidity (G) of $S_3$ was the highest followed by that of $S_4$, $S_1$, and $S_2$. Compact structure of union-blended fabric with more weight gave higher shear rigidity values. The intimate-blended fabrics showed high shear rigidity in the warp direction as the yarns used were 2 ply. Shear rigidity in the weft direction of union-blended fabrics was more in comparison to their warp counterparts as the pure wool used in these showed less shear rigidity in warp direction as compared to blended yarn used in weft. Kariyappa et al. (2010) also observed higher shear stiffness of eri fabric as compared to wool due to its triangular cross section which has high frictional force. A similar trend was observed for hysteresis of shear force at 0.5° and 5°. Compact fabric structure of union-blended fabrics was responsible for their higher 2HG and 2HG5 values.

***Surface properties.*** Surface characteristics of fabric were presented through coefficient of friction (MIU) which shows lowest value for $S_4$ in both the warp and the weft directions, followed by $S_3$, in the warp direction. The intimate-blended fabric showed slightly higher friction due to high percentage of silk that creates smoothness and more contact area with the contactor. Higher coefficient of friction corresepond to smoother surfaces (Lima et al. 2009).Union-blended fabrics consisted of pure wool in the warp direction that showed lower coefficient of friction in both the directions except weftwise $S_3$ fabric. MMD indicates the variation in MIU. Fabric $S_4$ showed more weftwise variation in comparison to all other fabrics.

The results showed that there was very less geometric roughness in all the fabrics. Fabric $S_4$ had the least warpwise geometric roughness followed by $S_3$, geometric roughness of intimate-blended fabric was slightly more due to higher silk content. The results are in line with those reported by Kariyappa et al. (2007) who found that *eri* fabric was tougher than wool due to silk's flat cross section.

***Compression properties (LC).*** The value of compressibility (LC) that provides a feeling of bulkiness and spongy property to the fabric was the highest for $S_1$ implying that it was highly compressible. This was followed by $S_3$ since the LC values are dependent on compressional characteristics of yarns, the intimate-blended as well as union-blended fabrics made from finer counts (25 tex) showed slightly lesser values of LC.

In line with the compression properties, that determine the resilience, $S_1$ showed highest resilience followed by $S_2$, $S_4$ while $S_3$ had lowest resilience among all the fabrics.

Compressional energy increases with increase in thickness of the fabric as the thickness of fabric $S_3$ at 0.5 gf was the highest, followed by $S_4$ and $S_1$ whereas fabric $S_2$ showed the least thickness. A similar trend was observed when the thickness of fabrics was measured at of 50 gf.

Consequently, the highest compressional energy was found in $S_3$ fabric followed by $S_1$. It was attributed to more thickness of the samples that it required more energy to compress. The fiber to fiber slippage was found to be more among the blended fabrics due to 65% of silk in the yarn. According to the Nayak et al. (2009), when fiber to fiber slippage increases energy required to compress the fabric decreases. Fabric $S_4$ showed the least compressional energy followed by $S_2$.

***Weight (W).*** Going with the trend, weight of $S_3$ was found to be more followed by $S_4$, $S_1$, and $S_2$ had lowest weight.

***Primary hand values and total hand values of developed fabrics.*** The primary and total hand values of the developed fabrics in terms of koshi, shari, fukumari, numeri, hari, sofutosa have been presented in the Table 6. The scale used for PHV was 10-srongest, 5-medium, and 1-weakest while it was 5-excellent, 4-good, 3-average, 2-fair, 1-poor for THV.

**Table 6.** Primary and total hand values of the developed fabrics.

| | Primary hand values | | | |
|---|---|---|---|---|
| Properties | $S_1$ | $S_2$ | $S_3$ | $S_4$ |
| Men's suiting (Winter) | | | | |
| Koshi | −1.31 | −1.79 | 2.61 | 1.47 |
| Numeri | 9.31 | 9.32 | 7.76 | 8.32 |
| Fukurami | 9.34 | 9.24 | 8.49 | 8.76 |
| Total hand value (THV) | 2.81 | 2.42 | 3.90 | 3.76 |
| Men's suiting (Summer) | | | | |
| Koshi | −1.24 | −2.02 | 2.83 | 1.57 |
| Shari | −0.47 | −1.13 | 0.95 | 0.12 |
| Fukurami | 3.93 | 4.36 | 5.28 | 4.81 |
| Hari | −0.98 | −1.78 | 3.56 | 2.19 |
| Total hand value (THV) | −0.35 | −1.29 | 1.48 | 0.74 |
| Women's suiting (Winter) | | | | |
| Koshi | 2.68 | 2.46 | 4.72 | 4.11 |
| Numeri | 7.38 | 7.38 | 6.50 | 6.82 |
| Fukurami | 7.03 | 7.10 | 6.60 | 6.75 |
| Sofutosa | 7.48 | 7.51 | 5.42 | 6.00 |
| Total hand value (THV) | 3.90 | 3.82 | 3.94 | 3.99 |
| Women's thin dress material (Winter) | | | | |
| Koshi | 4.80 | 4.63 | 6.22 | 5.80 |
| Numeri | 9.12 | 9.15 | 8.61 | 8.83 |
| Fukurami | 11.57 | 11.69 | 11.30 | 11.45 |
| Total hand value (THV) | 6.38 | 6.36 | 6.12 | 6.37 |

Hand value of primary handJapanese termEnglish Equivalent
10—strongest, 5—medium, 1—weakest Koshi Stiffness
Total hand value (THV) Shari Crispness
5—Excellent, 4—Good, 3—Average, 2—Fair, 1—Poor Fukumari Fullness and Softness
Numeri Smoothness
Hari Antidrape stiffness
Sofutosa Soft touch

$S_1$ = Intimate-blended fabric made from 65s/35w, 2/33 × 33 tex yarn.
$S_2$ = Intimate-blended fabric made from 65s/35w, 2/25 × 25 tex yarn.
$S_3$ = Union-blended fabric made from 100w × 65s/35w, 2/33 × 33 tex yarn.
$S_4$ = Union-blended fabric made from 100w × 65s/35w, 2/25 × 25 tex yarn,

The data elicit that all the intimate-blended as well as union-blended fabrics were most suitable for women's light weight dress materials. Fabrics were also suitable for women's winter suitings. Union-blended fabrics were found to suitable for men's winter suitings. Furthermore, these were found to be least suitable for men's summer suitings.

In terms of men's winter suitings, the value of Koshi (stiffness) was found to be highest for $S_3$ followed by $S_4$. It was negative for $S_1$ as well as $S_2$ implying inadequate stiffness for men's winter suitings. The higher value of $S_3$ was attributed to the higher bending rigidity of woolen fiber accompanied by higher shear rigidity (G) and tensile resilience (RC). Both the intimate-blended fabrics showed the highest Numeri (smoothness) value. This can be attributed to the decrease in tensile and compressional energy as well as increase in tensile resilience of intimate blended fabrics. Fukumari (fullness and softness) is the bulky, rich and well-formed feeling. The value of intimate-blended fabric in $S_1$ was the strongest feeling followed by $S_2$ and $S_4$. The total hand value of fabrics was estimated from the primary hand values using Kawabata system of equations. The THV values were the highest for $S_3$ fabrics that got the feeling grade 'good' followed by $S_4$ fabrics was also graded as 'good', $S_1$ was 'average,' and that of $S_2$ was 'average/fair'.

When the fabrics were evaluated for men's summer suitings, it was found that Koshi (stiffness) and Shari (crispness) and Hari (antidrape stiffness) values were negative for both the $S_1$ and $S_2$ intimate-blended fabrics implying no feeling, whereas week feeling of Koshi Shari and Hari was observed in union-blended fabrics. However, Fukumari of both the union-blended fabrics showed medium feeling and approaching to medium for intimate-blended fabrics. Total hand value of the two intimate blended fabrics and $S_4$ was found not adequate for men's summer suitings while the total hand value was found poor for $S_3$ fabrics.

As far as tests for women's suitings (winter) were concerned, $S_3$ showed highest value of Koshi (medium) followed by $S_4$, $S_1$, and $S_2$ that had 'weak' Koshi value. Numeri value of intimate-blended fabrics was the highest meaning a strong feeling. Fukumari of $S_2$ intimate-blended fabric was the highest 'strong feeling' followed by $S_1$ (strong feeling). Though the values were lower for union-blended fabrics the feeling was the strong here as well. Sample $S_2$ also had highest Sofutosa (soft touch) value (strong feeling) preceded by $S_1$ (strong feeling), $S_4$ while $S_3$ had the lowest value of 5.42 (medium feeling). Total hand value for all the fabrics was found to be good. Amongst these, $S_4$ showed the highest THV followed by $S_3$, $S_1$, and $S_2$ fabrics.



## Analysis of thermal comfort properties

Table 7 shows the thermal comfort properties of the fabrics. It has been observed that the air permeability decreases with increase in wool content. Union-blended fabrics with 100% warpwise wool showed less transmission as compared to intimate-blended fabrics. This may attributed to the air entrapped within the porous structure of wool fiber. Fabric $S_3$ showed lowest air transmission due to the more compact structure of fabric because of high density of wool fiber, high linear density of yarns used which further contributed in increased thickness, mass, and fabric cover. The fabrics

**Table 7.** Thermal comfort properties of fabrics.

| Properties | $S_1$ | $S_2$ | $S_3$ | $S_4$ |
|---|---|---|---|---|
| Air permeability cc/sec/cm$^2$ | 96.8 | 119.3 | 57.4 | 68.0 |
| Moisture vapor transmission g/cm$^2$/24 h | 15.2 | 17.6 | 13.2 | 14.6 |
| Thermal insulation (Tog) | 0.6 | 0.4 | 1.0 | 0.8 |

$S_1$ = Intimate-blended fabric made from 65s/35w, 2/33 × 33 tex yarn.
$S_2$ = Intimate-blended fabric made from 65s/35w, 2/25 × 25 tex yarn.
$S_3$ = Union-blended fabric made from 100w × 65s/35w, 2/33 × 33 tex yarn.
$S_4$ = Union-blended fabric made from 100 w x 65s/35w, 2/25 × 25 tex yarn.

made with the low-density fiber (silk) and yarns with less linear densities (25 tex) showed better permeability. $S_2$ showed very good air transmission properties. Thermal insulation plays a major role in maintaining the heat balance between the body and the environment. The main function of clothing in winter should be heat conservation. It has been observed that the thermal insulation increases with the wool content, thickness and bulk density in the fabric. Higher the air permeability lower the thermal insulation and vice versa. Union-blended fabrics shows good thermal insulation. Fabric $S_3$ showed highest value for thermal insulation due to high density of wool, higher linear density of yarns (33 tex) used in fabric construction that led to increased fabric thickness, mass, cover; finally resulted in more compact fabric structure. Moisture vapor transfer is the ability of the fabric to transfer the perspiration in the form of moisture vapor through it. It was observed that moisture vapor transfer decreases with increase in linear densities of fiber and yarn, thickness, square mass, and fabric cover. Intimate-blended fabrics and union-blended fabric $S_4$ showed very good moisture vapor transfer properties. This may be due to fineness of fiber and related higher specific surface area of silk and crimp-related openness in structure and hygroscopic nature of wool fiber itself. Also, both the fibers are hydrophilic hence, moisture was jammed into the fibers therefore giving comparatively cooler feeling as compared to the $S_3$ union-blended fabric which showed low moisture vapor transmission. As per increase in square mass, there is a decrease in the water vapor permeability in wool fabrics (Bogusławska et al. 2013).



### *Analysis of physiological comfort*

The effect of fiber/yarn composition and structure were analyzed to know the comfort behavior of the developed intimate-blended as well union-blended fabrics. The fabrics were subjectively evaluated as perceived by perspective consumers for hand value as well as to study the end use application of the fabrics.

The higher composition of wool in union-blended fabrics showed the higher THV values which are suitable for men's winter sutings and women's winter light weight dress material and suitings. This can be attributed to the bulk of the fabric which is too high and a higher compressibility is responsible for higher THV. The higher cloth cover, thickness, and crimped configuration of wool in union-blended fabrics are responsible for thermal insulation that makes comfortable winter suitings. The intimate-blended fabrics are suitable for women's winter light weight dress material and suitings due to the more softness, smoothness, lusture, less bending rigidity, good water and air transmission along with the thermal insulation due to wool content. The crimp of wool and scaly structure of fiber caused porosity in the wool-blended yarns and fabrics which are responsible for their excellent thermal properties Behra and Mishra (2007). The use of 2 ply yarn in warp for all the fabrics is responsible for higher THV values for winter. This may be attributed to the higher packing density of 2-ply yarns arising from the twisting operation during doubling. The handle of intimate-blended fabrics and $S_4$ union-blended (linear density 25 tex) fabric found better due to less compactness, thickness, and bulk.

### *Analysis of developed fabrics for hand value based on expert opinion*

Data furnished in Table 8 presents the consumer's acceptability of $S_1$ fabrics pertaining to texture, luster, tactile sensation, and aesthetic appearance according to expert's opinion. It was observed that most of the judges preferred $S_1$ fabric as compared to $S_2$ fabric. This may be due its better thermal insulation properties, more cloth cover as compared to the fabric $S_2$. The breaking during weaving was occurred more in the fabric $S_2$ due to the yarns used had less linear density and evenness. The $S_1$ fabric was found excellent in terms of aesthetic appearance and very good on other parameters viz. smoothness, softness, uniformity, luster and tactile sensation. Its pebbly texture was graded between good and very good. Fabric $S_1$ found significantly different ($p \leq .05$) from $S_2$ in terms of smoothness, uniformity, and aesthetic appearance.

Table 8. Analysis of developed fabrics for hand value based on expert opinion ($n$ = 30).

| | Intimate-blended fabrics | | | | Union-blended fabrics | | | |
|---|---|---|---|---|---|---|---|---|
| | s:w $S_1$ | s: w $S_2$ | | | 100w × s: w $S_3$ | 100w × s: w $S_4$ | | |
| Parameters | Median | Median | Wstat | $p$-Value | Median | Median | Wstat | $p$-Value |
| Texture | | | | | | | | |
| Smoothness | 4.00 | 3.00 | 11.05 | 0.0028* | 3.00 | 4.00 | 721.0 | 0.0025* |
| Softness | 4.00 | 4.00 | 104.5 | 0.0172 | 3.50 | 4.00 | 692.5 | 0.0005* |
| Pebbly texture | 3.50 | 3.00 | 992.5 | 0.2323 | 4.00 | 4.00 | 928.0 | 0.8442 |
| Uniformity | 4.00 | 3.00 | 1102.5 | 0.0026* | 3.00 | 3.00 | 882.5 | 0.6229 |
| Lustre | 4.00 | 4.00 | 1061.5 | 0.0225 | 3.00 | 4.00 | 822.0 | 0.1559 |
| Tactile sensation | 4.00 | 4.00 | 996.0 | 0.1945 | 4.00 | 4.00 | 842.0 | 0.2389 |
| Aesthetic appearance | 5.00 | 4.00 | 1112.5 | 0.0019* | 3.50 | 4.00 | 867.5 | 0.4638 |

$p$ = probability value derived from Mann–Whitney $U$ test, *Significant at 5% level of significance.
*Significant at 5% level of significance.
$S_1$ = Intimate-blended fabric made from 65s/35w, 2/33 × 33 tex yarn.
$S_2$ = Intimate-blended fabric made from 65s/35w, 2/25 × 25 tex yarn.
$S_3$ = Union-blended fabric made from 100w × 65s/35w, 2/33 × 33 tex yarn.
$S_4$ = Union-blended fabric made from 100w × 65s/35w, 2/25 × 25 tex yarn.



Among the union-blended fabrics, judges preferred $S_4$. This may be due to its finer count and less fabric thickness with better cloth cover as compared to $S_3$ fabric. The $S_4$ was found very good on all the parameters except uniformity. In terms of texture as far as smoothness and softness of fabrics was concerned $S_4$ was found significantly different ($p \leq .05$) from $S_3$.

### Analysis of intimate and union-blended fabrics for end use application based on expert opinion

For women's apparel, the respondents preferred $S_1$, $S_2$, and $S_4$ fabrics for making stoles, whereas $S_3$ fabrics for making shawls. For men's apparel the $S_1$ and $S_3$ fabrics were preferred most for *lohis* whereas $S_2$ and $S_4$ fabrics were preferred for mufflers. For home textiles, $S_1$ fabric was preferred for both the throws and *Khes*, $S_2$ was preferred for throws, whereas $S_3$ and $S_4$ fabrics were again preferred for *Khes* (Table 9).

### Estimation of cost per meter of intimate- and union-blended fabrics

The estimated cost of intimate-blended fabric developed in 65s:35w was 1631.30 Rs per meter whereas the cost of developed union-blended fabric was 1582 Rs per meter. The higher cost of weaving could be attributed to the late production due to more yarn breaks get required frequent manual removal of stuck slubs. However, as the wool content increased, the number of breaks in the weaving decreased, concludes that it is easier to weave mulberry silk waste when it is blended with a fiber having less variable diameter or keeping the 100% wool in the warp direction for constructing union-blended fabrics. The costs can be brought down by scaling up the production. Such cost-effective handloom intimate and union-blended fabrics has the potential to enhance domestic and export earnings of the handloom weavers.

## Conclusion

Mulberry silk waste and medium wool (24 microns) blended at the gillbox stage to prepare yarns of 33 and 25 tex on a worsted spinning system. The 65s:35w blended yarn for both the 33 tex and 25 tex counts was taken as optimum blend due to its higher strength, lesser hairiness, and significantly improved ($p \leq .05$) evenness as compared to pure silk. Also, silk will provide the cooler contact feeling as compared to pure wool. Intimate- and union-blended fabrics made from

**Table 9.** Analysis of intimate- and union-blended fabrics for end use application based on expert opinion.

| | s:w $S_1$ | | s:w $S_2$ | | 100w × s:w S3 | | 100w × s:w S4 | |
|---|---|---|---|---|---|---|---|---|
| End Uses | Weighted mean scores (WMS) | Ranks | Weighted mean scores (WMS) | Ranks | Weighted mean scores (WMS) | Ranks | Weighted mean scores (WMS) | Ranks |
| Women's apparels | | | | | | | | |
| Jackets | 2.13 | V | 1.96 | V | 2.26 | V | 2.20 | V |
| Shawls | 3.43 | II | 2.93 | IV | 3.56 | I | 2.83 | IV |
| Stoles | 3.86 | I | 4.00 | I | 3.46 | II | 3.76 | I |
| Mufflers | 2.90 | III | 3.66 | II | 3.10 | III | 3.23 | III |
| Shirt's/women's suiting | 2.16 | IV | 3.06 | III | 2.63 | IV | 3.43 | II |
| Men's apparel | | | | | | | | |
| Jackets | 2.13 | V | 2.60 | IV | 2.60 | IV | 2.70 | IV |
| Coats | 2.30 | IV | 1.76 | V | 2.30 | V | 2.43 | V |
| Mufflers | 3.46 | I | 4.20 | I | 3.63 | II | 3.60 | I |
| *Sherwanis/Achkan* | 2.88 | III | 2.86 | III | 3.16 | III | 3.23 | III |
| *Lohis* | 3.60 | II | 3.83 | II | 3.66 | I | 3.30 | II |
| Home textiles | | | | | | | | |
| Throws | 2.86 | I | 2.93 | I | 2.43 | III | 2.40 | IV |
| Curtains | 2.60 | II | 2.56 | III | 2.36 | IV | 2.46 | III |
| Cushion covers | 2.33 | III | 2.20 | IV | 2.53 | II | 2.76 | II |
| *Khes*/light weight woolen sheet | 2.86 | I | 2.83 | II | 2.63 | I | 2.90 | I |

$S_1$ = Intimate-blended fabric made from 65s/35w, 2/33 × 33 tex yarn.
$S_2$ = Intimate-blended fabric made from 65s/35w, 2/25 × 25 tex yarn.
$S_3$ = Union-blended fabric made from 100w × s/w, 2/33 × 33 tex yarn.
$S_4$ = Union-blended fabric made from 100w × s/w, 2/25 × 25 tex yarn.

33 tex yarn counts had high compression and high bending rigidity. $S_1$ (65s/35w, yarn count 2/33 × 33 tex) and $S_2$ (65s/35w, yarn count 2/25 × 25 tex) had higher resilience as well as warpwise extensibility whereas $S_3$ (100w × 65s/35w, yarn count 2/33 × 33 tex) and $S_4$ (100w × 65s/35w, yarn count 2/25 × 25 tex) had high bending hysteresis, high tensile energy, lower coefficient of friction, and less geometric roughness. Good air permeability and moisture vapor transfer properties were found in intimate-blended fabrics, whereas union-blended fabrics shows good thermal insulation property. The intimate- and union-blended fabrics with less yarn linear density as well as low pick density shows good transmission against air and water. Intimate-blended fabrics made from both the counts and union-blended fabric exhibiting the linear density 25 tex provide more physiological comfort. Total hand value of both intimate- and union-blended fabrics was excellent for women's light weight dress material and good for women's winter suitings. Intimate-blended fabrics made from both the counts and the union-blended fabric with the yarn count 2/25 × 25 tex are recommended for use as shawls and stoles for women's wear. *Lohis* and mufflers can be the suitable end uses among men's wear. The fabric made from 2/33 × 33 tex union blend is recommended for home textiles such as throws and *khes*. Total hand value for union-blended fabrics was found good for men's winter suitings. The estimated cost of intimate-blended fabric developed in 65s:35w was 1631.30 Rs per meter, whereas the cost of developed union blended fabric was 1582 Rs per meter. The costs can be brought down by scaling up the production. Such cost-effective handloom intimate- and union-blended fabrics have the potential to enhance domestic and export earnings of the handloom weavers, thereby strengthening their income generating capacity.

## References

Behra, B. K., and R. Mishra. 2007. Comfort properties of non conventional light weight worsted suiting fabrics. *Indian Journal of Fibre & Textile Research* 32: 72–79.

Bogusławska Bączek, M., and L. Hes. 2013. Effective water vapour permeability of wet wool fabric and blended fabrics. *FIBRES & TEXTILES in Eastern Europe* 21(1): 67–71.
Datta, R. K., and N. C. Patel. 1995. Fabric feel, and appearance of some Indian suiting fabrics using Kawabata instrument. *ATIRA Communications on Textiles* 29: 22–35.
Kariyappa, N. S. S., G. N. Ramaswamy, S. Roy, T. H. Somashekhar, and R. P. M. Damodara. 2007. Effect of mechanical raising on low stress, surface properties total hand value of white eri spun silk fabric. *Man Made Textiles in India* 50:54–57.
Kariyappa, K. P. S., R. P. M. Damodara, R. Subrata, and T. H. Somashekhar. 2010. Evaluation of low stress, surface properties and total hand value of red eri spun silk fabric. *Man Made Textiles in India* 53:54–57.
Kawabata, S., and M. Niwa. 1975. Fifth International Wool Textile Research Conference Aachen, 5, 413.
Kumar R., R. Chattopadhyay, and I. C. Sharma. 2001. Feasibility of spinning silk/silk blends on cotton system. Textile Asia 32: 27–31.
Lima, M., M. Rosa, S. L. F. Vasconcelos, and J. Cunha. 2009. Fabrics made from non-conventional blends: What can we expect from them related to frictional properties? *Textile Research Journal* 79(4): 337–42. doi:10.1177/0040517508097519.
Nayak, R. K., S. K. Punj, K. N. Chatterjee, and B. K. Behra. 2009. Comfort properties of suiting fabrics. *Indian Journal of Fibre & Textile Research* 34: 122–128.
Pac, M. J., M.-A. Bueno, M. Renner, and S. El Kasmi. 2001. Warm-cool feeling relative to tribological properties of fabrics. *Textile Research Journal* 71(9): 806–812. doi:10.1177/004051750107100910.
Tyagi, G. K., K.P. Sharma, A. Goyal, and M. Singh 2004. Variation in polyester-viscous and polyester-cotton ring and rotor yarn characteristics as a consequence of fibre cross-section. *Indian Journal of Fibre and Textile Research* 29: 184–89.
Verma, N., and N. Grewal. 2011. Fibre characteristics of mulberry silk waste and Australian merino wool for developing blends. *Journal of Research* 48(1 and 2): 96–100.