Yak cashmere is one of the natural animal fibres produced from the yak, which mainly grows on the Tibetan plateau of China, and comprises 85% of the world’s total production [1]. There are some excellent properties of yak cashmere, such as comparing to cashmere fibre with same fineness, the density of yak cashmere fibre scales is larger and the thickness smaller, making the warmth retention higher [2]. Meanwhile the tactility of yak cashmere is smoother and the scratchiness less comparing with cashmere fibre. Furthermore the price of yak cashmere is only 1/3 that of cashmere, leading to greater profit margins. These excellent properties make yak cashmere a good substitute for cashmere fibre. Therefore, recently yak cashmere has attracted more and more attentions for textile processing due to its excellent properties, environmentally friendly characteristics and inexpensive prices [3].

However, there are some difficulties in the direct textile processing of yak cashmere, especially pure yarn spinning, since the dispersion of the fibre length is large [4]. Therefore in practical spinning, some other fibres were employed for yak cashmere spinning which can make up for the deficiency of yak cashmere. In general, some natural fibres, such as cotton and cellulose fibre, were employed, and corresponding blend yarns were spun. In the paper, cotton fibres were used, and blend yarns with three different kinds of blending ratios; 70/30, 50/50 and 30/70 were spun. The properties of corresponding knitted fabric were also studied. The effects of the blending ratios on the yarn and knitted fabric were mainly investigated.

Compact spinning is one of the most widely used of the new kinds of modified ring spinning methods, in which one kind of fibre condensing device is employed on a ring spinning frame in order to decrease the spinning triangles and improve the spun yarn qualities [5-7]. Compact spinning with a lattice apron is the most widely used compact spinning method at present, as well as 3-line roller compact spinning and 4-line roller compact spinning [8]. In this kind of compact spinning, a lattice apron was used for fibre condensing. Sirospun spinning (Two-strand yarn spinning) is another new modified ring spinning method invented by the Division of Textile Industry laboratories of theCSIRO in Australia and IWS together in the years 1975~1976, which is conducted on a conventional ring frame by feeding two rovings into the apron zone at a predetermined separation simultaneously, thereby improving yarn qualities, especially hairiness reduction [9, 10]. Therefore, in this paper, compact Sirospun blend yarns were spun on a ring spinning frame modified with a 4-line roller compact spinning device.

### Key words:
- yak cashmere, blend yarn, knitted fabric, blend ratio

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### Spinning experiment with compact sirospun blend yarn

**Spinning system**

Four-line compact spinning (FLCS) is one most widely used pneumatic compact spinning systems, which is primarily produced by the Toyota Company of Japan (see Figure 1). At present, this system can be produced in China with mature technology, and can be used for modification of a traditional ring spinning frame directly [11]. In the FLCS, there is one output roller at the front of the front roller, which is connected with the front roller via the carrier wheel. Correspondingly there is one output top roller above the output roller. An output nip is produced between the output roller and output top roller, and a front nip is produced between the front roller and front top roller. The area between the front nip and output nip is the condensing zone. In yarn spinning, the fibre strand coming from the draft zone is condensed in the condensing zone by the negative pressure airflow in the shaped tube. The width of the fibre strand is nearly equal to the diameter of the final yarn, and the spinning triangle is reduced greatly. Afterwards under the twist the fibre strands rotate around the axis, then the fibres on both sides fold gradually and roll into the centre of the spun yarn, and the final yarn is formed.

In the spinning process of Sirospun spinning, two rovings are fed into the apron zone at a predetermined separation size.
was employed, and yak cashmere and cotton blend yarns with three different kinds of blending ratios: 70/30, 50/50 and 30/70 were spun.

Experimental preparations
Combed roving of 500 tex (5 g/10m) with a twist factor of 128 was used as raw material. Then three types of compact Sirospun yarns of 20.8 tex (48 Nm), 18.5 tex (54 Nm), and 16.6 tex (60 Nm) with blending ratios of 70/30, 50/50 and 30/70 were spun. Parameters of the cotton fibre and yak cashmere chosen are shown in Table 1 and details of the spinning parameters – in Table 2.

Results
Taking ten bobbin yarns as measuring samples, all were placed under standard conditions of 20±3 °C and 65±3% RH for at least 24 hours before testing. Yarn hairiness, strength, evenness and the number of snarlings were measured. The test instruments were as follows: an Uster tester – 5-S800 evenness tester (Uster Technologies, Switzerland) and single yarn tester – YG068C (Suzhou Changfeng Textile Electromechanical Technology Co., Ltd., China). The yarn evenness and hairiness were evaluated once by the Uster tester – 5-S800 evenness tester at a speed of 400 m/min, with a test time of 1 minute, and the value obtained was accepted as the evenness and hairiness of this one bobbin yarn. The breaking force of yarns was also tested ten times on a YG068C fully automatic single yarn strength tester at a speed of 500 mm/min, and the average value of ten tested results was taken as the breaking force of this one bobbin yarn. Finally the average values of ten bobbin yarns were taken as the corresponding qualities of the spun yarn. Properties of the spun yarns measured are shown in Tables 3-5.

From Table 2, it is easy to see that with an increasing content of cotton, for the same yarn count spun, the negative pressure is the same, where the spindle speed can be increased, and the spinning efficiency is increased correspondingly. According to the results measured, shown in Tables 3-5, it is obvious that with an increase in the content of cotton, for the same yarn count spun, all properties tested were improved. That is, the addition of yak cashmere is not beneficial for spun yarn conventional qualities. The possible reason is that compared with cotton, the value of the length of yak cashmere is less and its dispersion larger, making the

Table 1. Fibre parameters.

| Fibre       | Tenacity, cN·dtex⁻¹ | Elongation, % | Linear density, dtex | Fibre length, mm |
|-------------|----------------------|---------------|----------------------|------------------|
| Yak cashmere| 4.63                 | 5.6           | 3.71                 | 30.5             |
| Cotton      | 2.33                 | 49.13         | 1.34                 | 37               |

Table 2. Spinning parameters.

| Yarn kind, tex | Draft multiple | Blending ratios | Negative pressure, Pa | Spindle speed, r/min |
|---------------|----------------|-----------------|-----------------------|----------------------|
| 20.8          | 48.01          | 70/30, 300      | 9300                  |
| 18.5          | 54.05          | 70/30, 2800     | 8800                  |
| 16.6          | 59.88          | 70/30, 2800     | 7300                  |
Table 3. Yarn properties of modified yarn 20.8 tex

| Blending ratios | H   | Strength, cN | Strength CV, % | Evenness CV, % | -50% Thin places, km | +50% Thick places, km | +200% Neps, km | Elongation, % | Twist, T·m⁻³ |
|-----------------|-----|--------------|----------------|---------------|----------------------|----------------------|--------------|--------------|-------------|
| 70/30           | 4.52| 219.4        | 10.7           | 13.1          | 11.8                 | 48.6                 | 52.1         | 4.96         | 745.2       |
| 50/50           | 4.19| 310.6        | 5.8            | 11.6          | 0.6                  | 22.3                 | 33.8         | 5.13         | 717.6       |
| 30/70           | 3.68| 391.7        | 3.6            | 10.3          | 0.1                  | 3                    | 8.7          | 5.99         | 692.1       |

Table 4. Yarn properties of modified yarn 18.5 tex.

| Blending ratios | H   | Strength, cN | Strength CV, % | Evenness CV, % | -50% Thin places, km | +50% Thick places, km | +200% Neps, km | Elongation, % | Twist, T·m⁻³ |
|-----------------|-----|--------------|----------------|---------------|----------------------|----------------------|--------------|--------------|-------------|
| 70/30           | 3.97| 184.8        | 12.9           | 14.5          | 19.2                 | 68.5                 | 82.3         | 5.12         | 801.3       |
| 50/50           | 3.67| 274.6        | 6.1            | 12.9          | 1.5                  | 43.5                 | 63.5         | 5.75         | 782.6       |
| 30/70           | 3.24| 356.4        | 4.5            | 11.6          | 0.3                  | 20                   | 35.3         | 6.14         | 724.4       |

Table 5. Yarn properties of modified yarn 16.6 tex.

| Blending ratios | H   | Strength, cN | Strength CV, % | Evenness CV, % | -50% Thin places, km | +50% Thick places, km | +200% Neps, km | Elongation, % | Twist, T·m⁻³ |
|-----------------|-----|--------------|----------------|---------------|----------------------|----------------------|--------------|--------------|-------------|
| 70/30           | 3.43| 162.3        | 15.1           | 15.9          | 33.1                 | 97.3                 | 103.4        | 5.23         | 896.0       |
| 50/50           | 3.16| 250.7        | 9.3            | 14.3          | 2.9                  | 71.6                 | 81.9         | 5.86         | 864.2       |
| 30/70           | 2.77| 321.1        | 6.8            | 12.9          | 0.7                  | 51                   | 56.1         | 6.21         | 803.6       |

addition of yak cashmere non-beneficial for blend yarn qualities. However, there are some excellent functional properties of yak cashmere, such as warmth retention, which would be reflected in the fabric. Therefore, in the following section, the properties of knitted fabric made of yak cashmere and cotton blend spun yarns were studied.

- Properties of knitted fabric

In this section, the properties of corresponding knitted fabric, including the permeability, thickness, static voltage, warmth retention, whiteness, water permeability, bursting strength, elastic recovery, tensile properties, drape, wear resistance, pilling, anti-ultraviolet resistant and bending stiffness were measured and comparatively analysed. Firstly 48 Nm yarns with blending ratios 70/30, 50/50 and 30/70 were used for fabric knitting, with details of the weaving parameters shown in Table 6. Then the properties of corresponding knitted fabric were measured and studied comparatively.

- Physical properties

Physical properties are the basic characteristics of fabric, and have a great direct influence on fabric wearability. Therefore, in the paper, the physical properties of the fabric, including thickness, weight per square meter, air permeability, anti-staticness, warmth retention, whiteness, water permeability, wear resistance, pilling, anti-ultraviolet resistance and bending stiffness were tested, and the results measured are shown in Table 7, where CV is the coefficient of variation of the test.

The thickness of the fabrics made of three different blend yarns was measured. The test instrument was the fabric thickness tester YG141D (Changzhou No. 2 Textile Instrument Factory Co., Ltd., China). From Table 7, it is shown that with an increasing content of yak cashmere, the thickness of fabrics de-

![Figure 3. Strength of yarns with different blending ratios under different linear densities.](image-url)
Air permeability is another important parameter of fabric wearability, which is mainly determined by the number and size of voids between the warp and weft. The air permeability of the knitted fabrics made of three different blend yarns were measured ten times for each fabric using the test instrument YB461E Fabric Air Permeability Tester (Changzhou No. 2 Textile Instrument Factory Co., Ltd., China), and the average value was taken as the test results. As shown in Table 7, we can see that with an increasing content of yak cashmere, the air permeability of the fabrics is increased. In Table 3, it is evident that with an increase in the content of yak cashmere, the hairiness of blend yarns increases, which makes the fabric bulk and potentially leads to larger fabric air permeability.

The anti-staticness of the fabric, including the static voltage and static voltage half-life, was tested using a YG606D flat fabric heat retention tester (Changzhou No. 2 Textile Instrument Factory Co., Ltd., China), with a preheating time of 30s and heating cycle of 5. From Table 7, it is easy to see that compared with the fabric made of 70/30 and 30/70 blend yarns, the heat transfer coefficient of the fabric made of 50/50 blend yarn is larger and the warmth retention rate smaller, i.e. the warmth retention is decreased. Meanwhile, compared with the fabric made of 30/70 blend yarn, the warmth retention of the fabric made of 70/30 yarn increases slightly. That is, the average weight distribution of yak cashmere and cotton is not beneficial for fabric warmth retention. Compared with cotton, more yak cashmere is more beneficial to improve fabric warmth retention.

The anti-ultraviolet resistance of the fabric, including the UVA, UVB and UPF, was tested using a YB912E tester (Wenzhou Darong Textile Instrument Co., Ltd., China). From Table 7, it is obvious that with an increasing content of yak cashmere, the UVA of the fabric increases, while the UPF decreases. That is, with an increasing content of yak cashmere, the anti-ultraviolet resistance of the fabric decreases.

The bending stiffness of the fabric in the radial and zonal direction was tested using a YG207, YG(B)340D, YG502N. From Table 7, it is obvious that with an increasing content of yak cashmere, the bending stiffness of the fabric increases.

The whiteness, water permeability, wear resistance and illing of the fabrics were also tested using a YG207 (Nan Tong Sansi Electromechanical Science & Technology Co., Ltd., China), which was calculated according to the equation $G = 9.8 \times \rho (0.5L)^{0.5}$, where $\rho$ is the weight per square meter of the fabrics and $L$ is the exertion length. Form Table 7, it is obvious that with an increasing content of yak cashmere, the bending stiffness of the fabric increases.

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| Properties | 70/30, CV/% | 50/50, CV/% | 30/70, CV/% |
|------------|------------|------------|------------|
| Thickness, mm | 0.63 [5.65] | 0.69 [4.97] | 0.70 [5.72] |
| Weight per square meter, g/m² | 173.6 | 180.2 | 180.8 |
| Air permeability, mm²/s | 2066.46 [7.49] | 1036.83 [4.27] | 1027.98 [4.39] |
| Antistaticness | Static voltage, V | 1684 | 1320 | 1233 |
| | Static voltage half-life, s | 1.24 | 1.24 | 1.09 |
| Warmth retention | Heat Transfer Coefficient, W/m²°C | 53.09 [14.8] | 59.91 [12.1] | 54.45 [12.8] |
| | Warmth retention rate, % | 24.98 [15.2] | 22.68 [13.2] | 24.40 [13.0] |
| | Clo value, 0.155 °C·m²/W | 0.12 [15.3] | 0.11 [12.9] | 0.12 [13.6] |
| Whiteness | | | |
| | | 76.57 [0.54] | 77.45 [0.43] | 78.44 [0.37] |
| Water permeability | | | |
| | | 212 [1.76] | 221 [1.95] | 232.25 [7.48] |
| Wear resistance, % | | | |
| | | 2.71 | 2.22 | 1.99 |
| Pilling | | | |
| | | 0.5 | 1.75 | 2.5 |
| Anti-ultraviolet resistant | UVA, % | 7.58 | 3.16 | 0.59 |
| | UVB, % | 0.54 | 0.46 | 0.41 |
| | UPF | 83.97 | 120.46 | 194.03 |
| Bending stiffness, mN·m | Radial | 0.024 | 0.019 | 0.011 |
| | Zonal | 0.0072 | 0.0034 | 0.0035 |

| Properties | 70/30, CV/% | 50/50, CV/% | 30/70, CV/% |
|------------|------------|------------|------------|
| Bursting strength, N | 453.2 [9.95] | 625.5 [3.27] | 751.2 [7.72] |
| Elastic recovery | Radial | 51.55 [4.75] | 59.12 [0.87] | 57.88 [8.71] |
| | Zonal | 62.28 [7.16] | 61.38 [4.23] | 52.77 [6.42] |
| Plastic deformation rate, % | Radial | 24.21 [5.03] | 20.41 [1.26] | 21.05 [6.38] |
| | Zonal | 18.85 [7.83] | 19.37 [5.43] | 23.61 [6.33] |
| Tensile property | Radial | 86.53 [11.72] | 143.83 [7.37] | 158.47 [8.86] |
| | Zonal | 62.73 [3.65] | 88.77 [3.81] | 99.6 [6.81] |
| Breaking elongation, % | Radial | 25.85 [4.10] | 35.84 [5.42] | 33.49 [5.12] |
| | Zonal | 40.67 [4.16] | 49.76 [10.96] | 46.67 [11.82] |
| Breaking work, J | Radial | 0.15 [9.63] | 0.33 [8.21] | 0.31 [5.54] |
| | Zonal | 0.19 [11.37] | 0.28 [6.66] | 0.32 [12.76] |
| Drape | Static drape coefficient, % | 36.17 [9.35] | 30.54 [4.32] | 32.36 [5.25] |
| | Ratio of dynamic and static drape coefficient | 0.995 [9.24] | 0.91 [8.44] | 1.18 [10.5] |
Mechanical properties

In the practice, the mechanical property of fabrics is also important and closely related to the wearability. Therefore, in the paper, the mechanical properties of the fabric, including the bursting strength, elastic recovery, tensile property and drape were tested, and the results measured are shown in Table 8, where CV is the coefficient of variation of the test.

Bursting strength is one of the most important evaluation parameters of fabric mechanical properties. The bursting strength of the fabrics made of three different blend yarns was measured with a fabric strength tester – HD036N (Changzhou No. 2 Textile Instrument Factory Co., Ltd., China), and the drawing speed was 100 mm/min. Meanwhile, the tensile properties, including the breaking strength, breaking elongation and breaking work in the radial and zonal directions, were tested with a HD026N fiber strength tester (Changzhou No. 2 Textile Instrument Factory Co., Ltd., China), where the drawing speed was 100 mm/min and pre-tension 2N. From Table 8, it is shown that with an increasing content of yak cashmere, the bursting strength of the fabrics decreases greatly, and the breaking strength and breaking work also decrease. That is, the addition of yak cashmere is not beneficial for fabric strength and elongation properties. Furthermore, the average weight distribution of yak cashmere and cotton is beneficial for improving the breaking elongation of the fabric.

The drape of the fabric, including the static drape coefficient and ratio of the dynamic and static drape coefficient, was tested using an XDP-1 Drape Tester (Shanghai New Fiber Instrument Co., Ltd., China). From Table 8, it is shown that compared with the fabric made of 70/30 and 30/70 blend yarns, the static drape coefficient and ratio of the dynamic and static drape coefficient of the fabric made of 50/50 blend yarn are both smaller, indicating that the fabric is softer.

Conclusions

In this paper, for overcoming the difficulty of direct yarn spinning of yak cashmere, cotton fibres were used, and yak cashmere and cotton blend yarns with three different kinds of blending ratios were spun. Three types of compact Sirospun yarns: 48 Nm, 54 Nm, and 60 Nm, with blending ratios 70/30, 50/50 and 30/70, were spun, and corresponding spun yarn qualities, hardness, breaking strength and evenness were tested. It is shown that with an increasing content of cotton, for the same yarn count spun, all properties tested were improved. That is, the addition of yak cashmere is not beneficial for spun yarn conventional qualities.

Then, taking 48 Nm yarns with blending ratios 70/30, 50/50 and 30/70 as an example, the physical properties and mechanical properties of corresponding knitted fabrics were tested and comparatively analysed. It is shown that with an increasing content of yak cashmere, the thickness and weight per square meter of the fabrics are both decreased, making the fabric lighter and thinner. Meanwhile, with an increasing content of yak cashmere, the air permeability, warmth retention, wear resistance and pilling of the fabric were all improved, while the strength and elongation properties and water permeability worsened. Further more the average weight distribution of yak cashmere and cotton in the yarn is beneficial for the fabric elastic recovery property and drape. That is, although the addition of yak cashmere is not beneficial for spun yarn conventional qualities, functional properties of the corresponding fabric would be improved.

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