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Sources of variation contributing to production and quality attributes of Kyrgyz cashmere in Osh and Naryn provinces: Implications for industry development

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ABSTRACT

We aimed to quantify the sources of variation contributing to the production and quality of cashmere produced in five districts in Osh and Naryn provinces of Kyrgyzstan. In early spring 2008 mid-side cashmere samples were taken from 719 cashmere adult females, and 41 cashmere adult males and castrates. Samples came from 53 villages and a total of 156 farmers' flocks. For 91 goats from 33 farmers in 13 villages of two districts that had been sampled earlier, cashmere was combed from the goat at the time of a second visit (end of April 2008) when the cashmere would normally be harvested. Following standard cashmere objective measurement, data were examined using general linear modelling to quantify the effects of potential determinants. The mean fibre diameter (MFD) of cashmere differed between provinces (Osh 15.7 μm, Naryn 16.7 μm; $P = 4.4 \times 10^{-20}$). About 42% of the cashmere was <16 μm, 48% was 16.0–18.0 μm and 9.5% was >18.0 μm. Most of the cashmere samples were coloured (81%), with 63% black and 19% white. The percentage of cashmere samples that were white declined as MFD increased (26% < 14 μm to 11% of >18 μm). The primary determinants of cashmere MFD of individual goats were age of goat (range 1.46 μm, $P = 1.8 \times 10^{-12}$) and farm (range 6.5 μm, $P = 1.7 \times 10^{-14}$). The lesser effects detected for sex (range 0.9 μm, $P = 0.026$) and colour of cashmere (range 1.8 μm, $P = 0.023$) were based on small sample sizes and are unreliable. Age of goat had important affects on fibre diameter variation (up to 1.7% in coefficient of variation, $P = 5.8 \times 10^{-6}$) and fibre curvature (2.5–5°/mm, $P = 2.1 \times 10^{-4}$). By far the greatest effect on fibre curvature was cashmere MFD ($P = 3.0 \times 10^{-104}$) with a smaller effect of sex (about 5°/mm, $P = 3.0 \times 10^{-6}$). Village effects were detected on fibre diameter variability (range 4.5% in coefficient of variation, $P = 0.027$) and fibre curvature (range 15°/mm, $P = 1.6 \times 10^{-7}$). There was a strong negative association between increasing MFD and declining fibre curvature (−5.11 ± 0.181°/mm per 1 μm; $P = 7.1 \times 10^{-121}$; $r^2 = 0.51$). Average combed cashmere weight was 164 g, the clean cashmere content was 0.661 and median clean cashmere production was 110 g per goat (range 60–351 g). Combed cashmere production increased with altitude of the village, probably related to different moulting times as spring temperatures warmed up later in higher altitude villages up to 3200 masl. Measurements of combed cashmere MFD were coarser than the mid-side samples taken earlier in the year. There are farmers and cashmere goats in the sampled districts of Kyrgyzstan which produce the finest qualities of commercial cashmere as the vast majority of cashmere is fine, has low variation in fibre diameter and has

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fibre crimping (curvature) typical of Chinese and Mongolian cashmere. There is substantial scope to increase the production and commercial value of cashmere produced by Kyrgyz goats. In particular, some villages and farmers need to change their buck selection practices if they wish to produce acceptable cashmere. Farmers should separate their finer and white cashmere prior to sale.

1. Introduction

The goat population in Kyrgyzstan was officially stated as 850,000 in 2007 (FAO, 2008). By comparison, the sheep population in 2007 was given as 3,198,000. A recent assessment in 12 villages in two of the study districts indicates that goat numbers are between three and five times higher than official district counts (Kerven and Toigonbaev, 2008). Local village officials and farmers in the study regions acknowledge that village goat populations are routinely under-enumerated, as farmers have to pay a higher head tax per goat compared with sheep.

Kyrgyzstan is close to the centre of origin of goats and therefore close to the origin of cashmere producing goats (French, 1970; Millar, 1986). However, the cashmere from Kyrgyzstan has not been characterised using statistical methods and sampling techniques before and its suitability for the international cashmere trade has not been technically assessed. Nevertheless, international cashmere buyers have been purchasing raw cashmere from Kyrgyz farmers at least since 2001. The potential to develop cashmere production as a new commercial industry for Kyrgyz pastoralists may provide new sources of income to remote families located in small mountainous villages far from western trade routes (Kerven et al., 2005). In the study region, goats are kept mainly for live animal sales to local markets, and for home consumption of meat. Sales of cashmere and are not viewed by the average farmers as a major source of income due to their small flock sizes (Kerven and Toigonbaev, 2009).

Cashmere is a luxury fibre used principally for clothing such as sweaters and woven fabric providing lightness and warmth. Cashmere is regarded by textile manufacturers and consumers as one of the softest and warmest natural fibres but it is rare, representing less than 0.01% of the world textile market. Cashmere needs special processing equipment to separate the downy fibres from the coarser guard hairs. Cashmere is regarded as an expensive fibre to purchase and process, compared to wool or cotton (Watkins and Buxton, 1992).

Raw harvested cashmere consists of a mixture of coarse guard hairs, fine downy cashmere fibres and naturally occurring contaminants such as wax (wool grease), suint (sweat), vegetable matter, scurf and soil. Cashmere quality is primarily determined by the diameter, length and the colour of the cashmere fibres (Schneider, 2008). In the field situation, traders assess the purity level of the raw greasy fibre to estimate the clean cashmere content and use the degree of cashmere fibre crimping (waviness) to estimate the mean fibre diameter in much the same way as has been used in the traditional wool industry. Fibre diameter is now objectively measured before apparel wool is sold using modern computer controlled laboratory equipment (Australian Wool Testing Authority, 2008). This equipment can also measure cashmere fibre curvature, which is the objective measurement of cashmere fibre crimp (McGregor, 2007) and is associated with cashmere softness (McGregor, 2000, 2004). While the use of fibre curvature is reliably associated with cashmere fibre diameter within a farm, it has been shown to be an unreliable indicator of cashmere fibre diameter when comparing between farms in Australia (McGregor and Butler, 2009).

The basic fleece colours of Kyrgyz goats are black, white and red with black-and-white marks on the body. Size is variable, with adult females averaging 44 kg and 90–95% of goats have horns. The fleece consists of clearly defined long, rough, coarse and lustrous guard hairs and a short downy undercoat (cashmere). The guard hair grows evenly all year round, reaching 15–17 cm in length and having a mean fibre diameter (MFD) of 70–90 μm. The inner cashmere coat grows in autumn and winter reaching a staple length of 4–5 cm and a MFD of 13–14 μm. Kyrgyz goats if shorn are usually shorn once a year in spring between the end of April and the first half of May, when the weather is warm. The total fleece weight ranges from 0.5 to 1 kg. Typical kidding rates are 125–150 kids per 100 does (Dmitriev and Ernst, 1989). Geographically, the goats located in southern Kyrgyzstan are almost pure native types (Osh and Batken Oblasts and some areas of Jalalabad) while in Naryn Oblasts and other northern provinces, they are mixed with introduced breeds following cross-breeding during the Soviet period.

During the Soviet period (ending in 1991), a new breed of goat was developed and introduced into state collective farms. This was the Don–Kyrgyz down breed, from crossing the local Kyrgyz goat with the Don breed from Russia (Dmitriev and Ernst, 1989). The fibre from Don goats is generally black with an average fibre harvest from does of 400–600 g, and from bucks 700–800 g. The coat of the Don breed consists of 65–75% down, 25–35% guard hair and small quantities of intermediate fibres. For every guard hair there are approximately 8–16 down fibres. Another characteristic of the Don goats' coat is that down grows longer than the guard hair. Average length of down fibres is 9–11 cm and average MFD 19–23 μm. The Don breed's fibre is characterised by elasticity and durability. It is used in knitting or crocheting dense Siberian shawls, which are still in demand.

In this study we aimed to quantify the sources of variation contributing to the production and quality of cashmere produced from modern Kyrgyz goats in two administrative provinces (Oblasts) and five districts of Kyrgyzstan. The socio-economic conditions of goat keepers in the study areas and the development of cashmere marketing chains are reported elsewhere (Kerven and Toigonbaev, 2009).

2. Materials and methods

2.1. Sources of samples

In late winter to early spring 2008 in Kyrgyzstan, samples were taken from 719 does (adult females), and 41 bucks (adult males) and castrates. These samples came from 53 villages in five districts (Rayons) of Kyrgyzstan as follows: Osh Oblast; Alay and Chong Alay sampled in February, and in Naryn Oblast; Naryn, Jumgal and Atbashy, sampled in March. One third of all villages in each district were sampled purposively, for geographical spread, in each ecological region and distance from main towns. A few villages were excluded from the military zone along the border with China. We aimed to sample 20 goats from each village representing flocks from 3 farmers. The goats were selected by the trained collectors, who were qualified livestock specialists. They randomly selected goats at least 1-year-old and upwards, of different coat colours from each flock, based on the available penned goats. The mean flock size of goats among households in the sampled villages is 7.7 (Kerven and Toigonbaev, 2009). In the two districts sampled in Osh Oblast, 54% of sampled farmers with smallstock (sheep and goats) had between 1 and 10 head and 27% had between 11 and 20 head (MSDSP, 2006). Goats represent 40–50% of the smallstock in these flocks. A total of 156 farmers from 53 villages provided goats for sampling. Samples of fleece containing guard hair and cashmere were taken from the mid-side site by cutting the fibre from a 3.1 cm × 3.1 cm square at skin level. Samples were stored in sealed plastic bags with identifying tag details. At the time of the visit the age of the goats was estimated by the collector based on incisor dentition, and the sex of the goat was recorded along with details of the village and farmer. Sampling (26 February–7th March 2008) was timed to coincide with the maximum cashmere growth prior to the seasonal moult.

For 91 goats from 33 farmers in 12 villages in two districts that had been sampled earlier, cashmere was combed from the entire fleece of the goat in a second visit (end of April 2008) when the cashmere from all goats was moulting and would normally be harvested by the farmers. The combed cashmere was weighed (g) and bagged. The altitude of the village was recorded.

2.2. Fibre testing

Fleece samples were sent to Yocom-McColl Testing Laboratories Inc., Denver, Colorado, USA, where the colour of the cashmere was visually determined. The samples were guillotined at the base (cut end) of the staples into 2 mm snippets, washed in solvent, dried, reconditioned under standard conditions for textiles and then tested using the optical fibre diameter analyser OFDA100 (IWTO-47, 2002). Measurements made were mean fibre diameter (MFD, μm), fibre diameter standard deviation (FDSD, μm), coefficient of variation of fibre diameter (CVD, %) and fibre curvature (FC, °/mm) using a fibre diameter cut-off of 27 μm for cashmere. This cut-off was chosen to avoid upward bias in the cashmere down measurements by the inclusion of coarser fibres that represented the guard hair fibre diameter distribution. This cut-off was determined based on inspection of fibre diameter distributions obtained from these fibre samples and is supported by analyses of cashmere fibre distribution curves (Couchman, 1984). For the samples of combed cashmere the samples were mini-cored, scoured and tested using the OFDA100. The cashmere yield of half ($n = 45$) the combed samples (CMyld, %, w/w) was determined using the OFDA100 based on the method of Peterson and Gherardi (1996) following 2 mm minicoring of samples. Clean cashmere production was determined as: combed cashmere weight × CMyld/100.

2.3. Statistical analysis

General linear models were used to detect any effect of Oblast and district on measured attributes of cashmere. However, when other terms such as age of goat, farmer or village are included in linear models, district ceases to be important or Oblast is aliased with other terms. Data were then examined with Oblast and district excluded using a general linear model with normal errors to determine the relationships between the MFD and any other potential determinant using GenStat Release 10.1 (Payne, 2007). The best model was developed with terms being added or rejected on the basis of *F*-tests. Samples without full details such as missing age were excluded from the model. The model has three outliers deleted as they were more than three standard deviations from the mean and appear to be either measurement or sampling errors or from goats not growing cashmere. The observational unit for the analysis was an individual goat. Goats whose age was recorded as 1.5 ($n = 6$) or 2.5 ($n = 1$) years were regarded as producing their second or third fleece respectively and included in the next highest age class. The data for fibre curvature and combed cashmere weight were transformed and analysed as $\log_{10}$(fibre curvature) to ensure that residual variance did not increase with age. Results are provided with the reference values related to farmer KA (village Kuiruchuk, District Jumgal) who had provided both buck and doe samples and whose cashmere had a MFD close to the average for the entire database.

Table 1
The main effects of Oblast and district of Kyrgyzstan on mean fibre diameter (MFD, μm), coefficient of variation of fibre diameter (CVD, %) and fibre curvature (FC, °/mm). Bold indicates *P*-value <0.05.

Oblast	MFD	CVD	FC	*n*
Osh	15.7	18.7	59.4	328
Naryn	16.6	19.7	56.3	432
Standard error of difference	0.15	0.24	1.08	
P-value	**4.4×10^{-20}**	**2.3×10^{-8}**	**6.1×10^{-9}**	
Additional significance of district				
Standard error of difference	0.14–0.24	0.23–0.39	1.05–1.73	
P-value	0.117	**0.00011**	**0.029**	

3. Results

For the measured attributes of cashmere the mean, standard deviation, maximum and minimum values are set out for different age classes, colours, sexes and districts of Kyrgyzstan in the Appendix A. The proportion of cashmere finer than 16 μm represented 42% of samples and cashmere coarser than 18.0 μm represented 9.5% of samples. The average cashmere MFD was 16.2 μm.

Black cashmere represented 63% of all samples and white cashmere represented 19% of all samples. The percentage that was white declined from 26% of cashmere finer than 14.0 μm to 11% of cashmere coarser than 18.0 μm. The proportion of goats with cashmere fibre curvature <45°/mm was 9.1%, 45–50°/mm 11.7% and >70.0°/mm was 10.4%.

3.1. Effect of Oblast and district

Oblast and district had significant effects on parameters measured (Table 1). There was a significant difference in cashmere MFD between Oblasts ($P = 4.4 \times 10^{-20}$) but not between districts within Oblasts ($P > 0.1$). Of farmers who had >2 goats sampled, those with a cashmere MFD < 15.0 μm were primarily from Osh (Osh 9 farmers, Naryn 2 farmers), while those with a cashmere MFD > 16.9 μm were primarily from Naryn (Osh 5 farmers, Naryn 19 farmers).

Oblast and to a lesser extent district had significant effects on cashmere CVD and FC (Table 1).

3.2. Other factors affecting cashmere quality

A range of factors affected cashmere quality and they are summarised in Table 2.

Table 2
The significance of factors affecting mean fibre diameter (MFD, μm), coefficient of variation of fibre diameter (CVD, %) and fibre curvature (FC, °/mm). Bold indicates *P*-value <0.05.

Factor	MFD	CVD	FC
Age of goat	**1.8×10^{-12}**	**5.8×10^{-6}**	**2.1×10^{-4}**
Sex of goat	**0.026**	0.313	**3.0×10^{-6}**
Farmer	**1.7×10^{-14}**	0.155	0.358
Village	0.652	**0.027**	**1.6×10^{-7}**
Colour of cashmere	**0.023**	0.172	0.526
MFD	–	[a]	**3.0×10^{-104}**

[a] Not tested as CVD is derived from MFD.

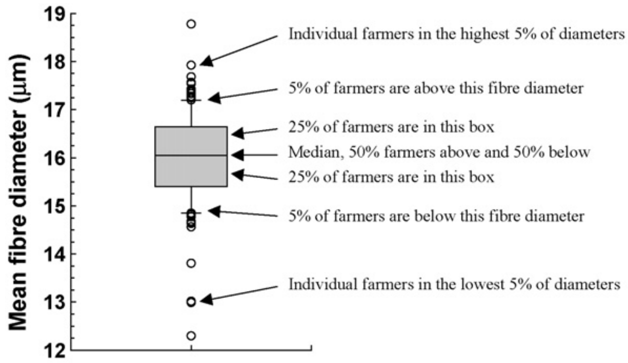

Fig. 1. A box plot showing the variability between farmers in the mean fibre diameter of cashmere after adjustment for sex and age of goat and colour of cashmere. Interpretation of the box plot is shown on the right.

3.2.1. Mean fibre diameter

The most parsimonious model for cashmere mean fibre diameter was:

$$\text{MFD} = \alpha + \beta_1 \text{ Age of goat} + \beta_2 \text{Farmer} + \beta_3 \text{Sex} + \beta_4 \text{Colour}$$

where the parameters β_1, β_2, β_3 and β_4 differ between age of goat, between farmer, between sex of goat and between colour of cashmere respectively. No additional effect of village, district or interaction between terms was detected ($P > 0.1$, Table 2). The percentage variance accounted for was 33.3% and the residual standard deviation was 1.11.

3.2.1.1. Effect of age. Increasing age from 1 year to 7 years of age resulted in significantly increased cashmere MFD (Table 3). Cashmere from goats aged 6 years old was 1.4 μm coarser than cashmere from goats aged 1-year-old. At age 8 there was no difference to Age 1 but total sample size was limited ($n = 4$, Appendix A) and data are therefore unreliable.

3.2.1.2. Effect of farmer. There were significant differences between farmers in cashmere MFD once adjustment was made for the age and sex of goat and for the colour of cashmere. The extent of differences between farmers is shown in Fig. 1 and farmers with the finest and coarsest cashmere are summarised in Table 4.

3.2.1.3. Effect of colour. A significant effect of colour of cashmere was detected once age and sex of goat and farmer was taken into account. While there was an indication that the red cashmere samples tested may be finer than other cashmere and that blue/grey cashmere samples tested may be coarser although there were few red and blue grey samples (Table 5) to be confident. More importantly was no difference in the MFD of black cashmere and white cashmere.

3.2.1.4. Effect of sex. There was a significant effect of sex of goat detected once age of goat, farmer and colour of cashmere were taken into account. While cashmere from does in the samples tested was significantly finer than cashmere from the bucks available for this study (Table 6), caution is needed in interpreting these data as the number

Table 3
The effect of age on cashmere mean fibre diameter. Estimates for ages greater than 1 are compared to the constant which is for an Age 1 buck with black cashmere from farmer KA (village Kuiruchuk, District Jumgal). Bold indicates *P*-value <0.05.

Age class	Estimate	s.e.	*P*-value	*n*
Constant	15.79	0.012	**<0.001**	133
Age 2	0.55	0.15	**<0.001**	182
Age 3	0.93	0.15	**<0.001**	181
Age 4	1.02	0.17	**<0.001**	113
Age 5	1.16	0.19	**<0.001**	72
Age 6	1.46	0.21	**<0.001**	50
Age 7	1.12	0.30	**<0.001**	21
Age 8	1.15	0.64	0.069	4

Table 4
The effect of farmer on cashmere mean fibre diameter. Farmers with significantly coarser and finer cashmere are compared to the constant which is for an Age 1 buck with black cashmere from farmer KA (village Kuiruchuk, District Jumgal). Bold indicates *P*-value <0.05.

Farmer	Estimate	s.e.	*P*-value
Constant	15.79	0.012	**<0.001**
Finer cashmere			
Finest 4 farmers	−1.98 to −3.49	0.93–1.24	**0.004–0.033**
Coarser cashmere			
Coarsest 10 farmers	+1.31 to +2.99	0.66–1.211	**0.002–0.046**

Table 5
The effect of colour on cashmere mean fibre diameter. Estimates for colour are compared to the constant which is for an Age 1 buck with black cashmere from farmer KA (village Kuiruchuk, District Jumgal). Bold indicates *P*-value <0.05.

Colour	Estimate	s.e.	*P*-value	*n*
Constant (black)	15.79	0.012	**<0.001**	476
Red	−1.11	0.48	**0.022**	8
Blue	0.69	0.33	**0.034**	17
White	0.19	0.13	0.150	147
Brown	0.69	0.49	0.161	7
Yellow	−0.18	0.23	0.433	48
Grey	0.12	0.22	0.573	53

Table 6
The effect of sex on cashmere mean fibre diameter. Estimates for sex are compared to the constant which is for an Age 1 buck with black cashmere from farmer KA (village Kuiruchuk, District Jumgal). Bold indicates *P*-value <0.05.

Sex	Estimate	s.e.	*P*-value	*n*
Constant	15.79	0.012	**<0.001**	35
Doe	−0.65	0.254	**0.011**	719
Castrate	−0.91	0.553	0.100	6

Table 7
The effect of age on cashmere fibre diameter coefficient of variation. Estimates for ages greater than 1 are compared to the constant which is for an Age 1 goat for village Akmoyun (District Atbashy). Bold indicates *P*-value <0.05.

Age class	Estimate	s.e.	*P*-value	*n*
Constant	19.88	0.525	**<0.001**	133
Age 2	−0.46	0.25	0.068	182
Age 3	−0.92	0.25	**<0.001**	181
Age 4	−1.03	0.28	**<0.001**	113
Age 5	−1.23	0.31	**<0.001**	72
Age 6	−1.73	0.35	**<0.001**	50
Age 7	−1.27	0.50	**0.011**	21
Age 8	−2.08	1.06	0.051	4

of bucks and castrates available for this study were limited (Appendix A).

3.2.2. *Fibre diameter coefficient of variation*

The most parsimonious model for cashmere fibre diameter coefficient of variation (CVD) was:

$$\text{CVD} = \alpha + \beta_1 \text{Age of goat} + \beta_2 \text{Village}$$

where the parameters β_1, and β_2, differ between age of goat and between village respectively. No additional effect of district, farmer, sex of goat or colour of cashmere or interaction between terms was detected ($P > 0.1$, Table 2). The percentage variance accounted for was only 14.1% and the residual standard deviation was 2.01.

3.2.2.1. Effect of age. Increasing age from 2 years to 7 years of age resulted in significantly reduced cashmere CVD (Table 7). As the number of goats at ages 7 and 8 are limited the estimates are less reliable than those for ages 1–6 years.

3.2.2.2. Effect of village. There were significant differences between villages in cashmere CVD ($P < 0.05$, Table 2) once adjustment was made for the age of goat. The villages with the lowest and highest cashmere CVD are summarised in Table 8.

Table 8
The effect of village on cashmere fibre diameter coefficient of variation after adjustment for the effect of age. Examples of villages with significantly lower and higher fibre diameter coefficient of variation are compared to the constant which is for an Age 1 goat in village Akmoyun (District Atbashy). Bold indicates *P*-value <0.05.

Village	Estimate	s.e.	*P*-value	*n*
Constant	19.88	0.525	**<0.001**	18
Lower coefficient of variation				
Gulcha	−1.98	0.72	**0.006**	15
Akjou	−1.36	0.73	0.061	15
Askali	−1.28	0.72	0.077	14
Higher coefficient of variation				
Tasbashat	2.47	0.68	**<0.001**	18
Ozgorush	1.83	0.68	**0.007**	18
Saryoi	1.64	0.68	**0.016**	18

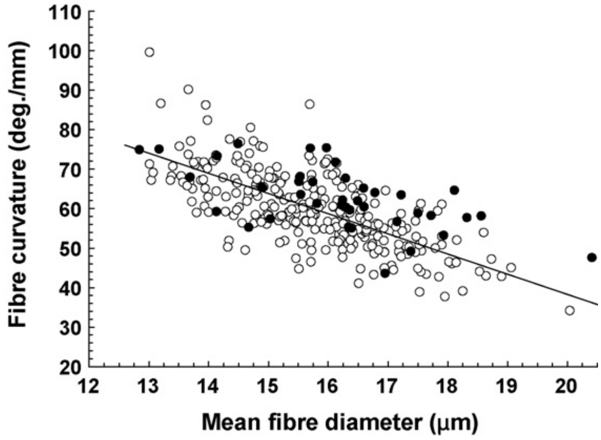

Fig. 2. The relationship between mean fibre diameter and fibre curvature for Kyrgyz cashmere. Symbols: does (○); bucks (●).

3.2.3. *Fibre curvature*

The most parsimonious model for $\log_{10}$ fibre curvature (log FC) was:

$$\text{Log FC} = \alpha + \beta_1 \text{ MFD} + \beta_2 \text{Sex} + \beta_3 \text{Age} + \beta_4 \text{Village}$$

where the parameters β_1, β_2, β_3 and β_4 differ between fibre diameter, between sex and age of goat and between village respectively. No additional effects of farmer, colour of cashmere or district or interaction between terms were detected ($P > 0.1$, Table 2). The percentage variance accounted for was 58.5% and the residual standard deviation was 0.0470. If MFD is not included in the analyses, the best model accounts for only 17.8% of the variation in fibre curvature.

3.2.3.1. Effect of MFD. The relationship between fibre curvature and MFD, without adjustment for age and sex of goat or village (Fig. 2, $P = 7.1 \times 10^{-121}$) was:

$$\text{Fibre curvature} = 140.5 - 5.11(\text{standard error } 0.181) \times \text{MFD}.$$

There was no significant curvilinear trend. This regression accounted for 51.4% of the variation and the residual standard deviation was 6.71.

3.2.3.2. Effect of sex. There was a significant effect of sex of goat once MFD and village were taken into account. Cashmere from does had significantly lower fibre curvature than cashmere from the bucks available for this study (Table 9). Caution is needed in interpreting these data as the number of bucks and castrates available for this study were limited.

3.2.3.3. Effect of village. There were significant differences between villages in cashmere fibre curvature once adjust-

Table 9
The effect of sex on $\log_{10}$ fibre curvature. Estimates for sex are compared to the constant which is for a 1-year-old buck from village Akmoyun (District Atbashy). Bold indicates *P*-value <0.05.

Sex	Estimate	s.e.	*P*-value	*n*
Constant	2.421	0.0291	**<0.001**	35
Doe	−0.0469	0.0092	**<0.001**	719
Castrate	−0.0401	0.0217	0.065	6

Table 10
The effect of village on $\log_{10}$ fibre curvature. Examples of villages with lower and significantly higher fibre curvature are compared to the constant which is for a 1-year-old buck from village Akmoyun (District Atbashy).

Village	Estimate	s.e.	*P*-value	*n*
Constant	2.421	0.0291	**<0.001**	18
Lower fibre curvature				
3 villages	−0.022 to −0.038	0.016–0.049	0.138–0.441	32
Higher fibre curvature				
2 villages	+0.067–0.079	0.016	**<0.001**	35
10 villages	+0.035–0.058	0.016–026	**0.002–0.035**	154

Bold indicates *P*-value <0.05.

Table 11
The effect of age on $\log_{10}$ fibre curvature. Estimates for ages greater than 1 are compared to the constant which is for a 1-year-old buck from village Akmoyun (District Atbashy). Bold indicates *P*-value <0.05.

Age class	Estimate	s.e.	*P*-value	*n*
Constant	2.421	0.0291	**<0.001**	133
Age 2	0.0079	0.0060	0.188	182
Age 3	0.0195	0.0061	**0.002**	181
Age 4	0.0241	0.0068	**<0.001**	113
Age 5	0.0311	0.0076	**<0.001**	72
Age 6	0.0178	0.0085	**0.036**	50
Age 7	0.0368	0.0118	**0.002**	21
Age 8	0.0295	0.0250	0.238	4

ment was made for MFD and the sex of goat. The villages with the lowest and highest cashmere fibre curvature are summarised in Table 10.

3.2.3.4. Effect of age. Increasing age from 2 years to 7 years of age resulted in significantly increased cashmere fibre curvature (Table 11). As the number of goats at ages 7 and 8 are limited the estimates are less reliable than those for 1–6 years of age.

3.3. Cashmere production

There were no factors that significantly affected clean cashmere weight. Cashmere production data are summarised in Table 12. The average combed fleece weighed was 164 g (range 60–351 g), and the average clean cashmere yield was 66.1%. The highest values for combed cashmere were greater than 300 g (see Fig. 3). These values provide an estimated average clean cashmere production of 164 × 0.661 = 108 g. For the goats where the actual clean cashmere production was measured, it averaged 119 g, with a median value of 110 g.

3.3.1. Combed cashmere weight and altitude of villages

The range in the altitude of the 12 villages where cashmere was harvested was 1540–3200 masl. The relationship between the $\log_{10}$ combed cashmere weight and the altitude of the villages (Fig. 3, $P < 0.001$) was:

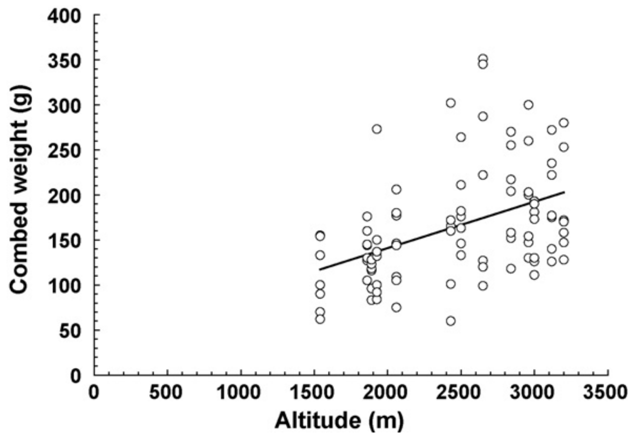

Fig. 3. The relationship between the altitude of villages where cashmere goats were farmed and the weight of combed cashmere harvested in March 2008. Each point represents an individual combed fleece.

$$\text{Log}_{10}(\text{Combed cashmere weight}) = 1.827(0.0711) + 0.000146(0.000028) \times \text{Altitude}.$$

There was no significant curvilinear trend and no other factor was significant. This regression accounted for 22.2% of the variation and the residual standard deviation was 0.144. The slope of the regression indicated that combed cashmere weight increased by 1.46% or approximately 5 g per 100 m increase in altitude. Cashmere yield was weakly associated with altitude, with cashmere yield declining 0.65% per 100 m increase in altitude ($P = 0.076$).

4. Discussion

4.1. Quality and production of Kyrgyz cashmere

The Oblast of origin of Kyrgyz cashmere had a significant effect on the mean fibre diameter of cashmere with the difference between 15.7 and 16.6 μm of large commercial importance. Cashmere from Osh Oblast has a MFD similar

Table 12
Combed cashmere weight, estimated clean cashmere weight, clean cashmere yield, mean fibre diameter (MFD), coefficient of variation of fibre diameter (CVD) and number of samples (*n*) tested for goats sampled in two districts of Kyrgyzstan.

District	Combed cashmere weight (g)	*n*	Clean cashmere weight (g)	Clean cashmere yield (%, w/w)	MFD (μm)	CVD (%)	*n*
Alay	163	71	122	65.6	16.8	19.9	33
Chong Alay	169	20	120	65.5	16.5	19.9	10

to premium cashmere from China whereas cashmere from Naryn Oblast would be less preferred for traditional hosiery textiles.

Overall, about 42% of the cashmere sampled was finer than 16 μm and suitable for knitwear. A further 48% of the cashmere was between 16.0 and 18.0 μm, similar to Iranian and Afghan cashmere, and suitable for either knitwear or weaving. Only 9.5% of samples were coarser than 18.0 μm and may only be suitable for weaving. Some of this coarser fibre could be cashgora (mixed with intermediate fibres), which has lower value than cashmere, but further examination is needed to confirm this.

Further, the average fibre diameter for combed cashmere was 16.8 μm. If this latter value is more typical for Kyrgyz cashmere then the cashmere will be reduced in value and less cashmere will be suitable for knitwear. The higher fibre diameter in combed cashmere may have resulted from sampling variation caused by using different goats, the loss of finer fibres during moulting or the testing procedure for the mid-side samples that was based on the base of the cashmere staples. The difference in MFD between mid-side samples and combed cashmere could also be due to the cashmere that grows at places other than at the mid-side site being coarser than the cashmere that grows on the mid-side. This pattern of fibre diameter variation within a fleece occurs with other breeds of cashmere goats (McGregor, 1994), mohair goats (Taddeo et al., 2000; McGregor and Butler, 2008c), alpacas (Aylan-Parker and McGregor, 2002) and Merino sheep (Turner et al., 1953) and so this pattern would be expected to occur with Kyrgyz cashmere goats.

The majority of the cashmere was coloured (81%) and the proportion of white cashmere declined from 26% of the finest cashmere to 11% of the coarsest cashmere. The high proportion of coloured cashmere is not unexpected in a largely unimproved population of native goats (Millar, 1986).

The analysis showed that there are other more important factors affecting cashmere quality than the district of Kyrgyzstan where the cashmere is grown. The variations in MFD were mainly due to differences between farmers' flocks and the different ages of the goats sampled. When comparing average results from farmers' flocks, there were differences of up to 6.5 μm in the MFD results, which would have large impacts on the commercial value of their cashmere. Primarily the farmers with the finer cashmere lived in the two sampled districts of Osh Oblast and those with the coarser cashmere lived in Naryn Oblast but there were farmers in each Oblast who had fine or coarse goats. Farmer effects on cashmere production and quality have been observed in other breeds (McGregor and Butler, 2008b).

The age of the goat affected MFD, fibre diameter variability and fibre curvature. This indicates that when combined with the effects of differences between farmers' flocks, some farmers have older goats that produce relatively coarser cashmere. However, it is not wise to cull older goats just on the basis of their age as older does are generally heavier and more fertile than younger lighter does. The impact of age is most probably associated with larger body size and its impact on reducing skin follicle density with the consequence that both primary and secondary skin follicles have reduced competition for nutrients enabling the follicles to increase in size (Maddocks and Jackson, 1988). Nutrition affects live body weight and both affect clean cashmere production (McGregor, 1988, 1992; McGregor and Umar, 2000; McGregor and Butler, 2008b).

Increasing the age of Kyrgyz goats from 1 year to 7 years was associated with a reduction in CVD. The potential importance of this reduction in CVD on the spinning and processing performance of cashmere can be estimated by using the function spinning fineness developed to predict the processing and spinning performance of wool (Butler and Dolling, 1995). Applying the spinning fineness formula to Kyrgyz cashmere indicates the variation in CVD related to age of goat is equal to about 0.2–0.4 μm in spinning fineness. There was also a difference between villages of up to 4.4% in CVD, equal to about 0.9 μm in spinning fineness. At the current state of the Kyrgyz cashmere industry these differences in CVD are not of commercial significance. It is likely that the estimates of CVD in the present work are less than those that would be obtained from testing commercial lots of combed cashmere, as the testing of the mid-side samples in the present work does not include variation in fibre diameter along the fibre (see Table 12 for within fleece CVD), between sites within the fleece, between animal within herds and amongst herds of cashmere goats. However, by using spinning fineness, which incorporates CVD, to assess the fibre diameter rather than only using MFD, breeders and purchases can use one objective measurement that incorporates both MFD and CVD.

While the results showed there were statistical differences between villages and age of goat on fibre diameter variability and fibre curvature, these effects are of little commercial significance at this point in time. The most important relationship was a strong negative relationship between fibre curvature and MFD, which accounted for 51% of the variation in fibre curvature, more than the 39% found in Australian cashmere goats (McGregor and Butler, 2009). Fibre curvature declined an average 5.1°/mm for a 1 μm increase in MFD, which is similar to the 5.8°/mm observed in Chinese Liaoning goats but less than the 13.6°/mm measured in controlled experiments with Australian goats (McGregor, 2003). In other words, as cashmere becomes coarser, it has less fibre crimping. This association has traditionally been used in field classing of cashmere into fibre diameter sale lots. Thus, buyers in the field can look at raw cashmere and be reasonably confident that more crimpy cashmere has finer diameter. This is a shortcut method to assess cashmere fibre diameter without having to send samples to a laboratory for testing.

Differences in cashmere fibre curvature due to village, sex and age of goat amounting to 7% of the variance are small in comparison with the impact of MFD on cashmere fibre curvature but suggest that there are local factors affecting cashmere growth that are important. Effects due to sex are small, equal to 5–6°/mm and these may be due to live weight and/or selection practices of farmers rather than any genetic affect *per se*. The effect of age on fibre curvature increases with age reaching 2.5–5.2°/mm between the ages of 3 and 8. The effect of age on fibre curvature is at its maximum equal to a decrease of about 1 μm in MFD. The effect of village on fibre curvature ranges from an increase of about 10°/mm to a reduction of about 5°/mm, equivalent to changes of 2 μm finer to 1 μm coarser in MFD. These changes at a village level may reflect differences in cashmere production as better fed goats grow more and longer cashmere that has lower fibre curvature or conversely poor fed goats grow less and shorter cashmere that has higher fibre curvature. These local factors could include differences in genetics, nutrition or management of goats. These results therefore indicate that using fibre curvature as a subjective measurement for fibre diameter will be more reliable within villages and within age classes of goats and less reliable if used across villages when selecting bucks for breeding or when sorting raw cashmere into homogenous batches of fibre for sale.

Cashmere fibre curvature is important as it is associated with cashmere production, the effect of reducing fibre curvature to below 70°/mm being to reduce the relative clean cashmere production (McGregor and Butler, 2008b). Higher cashmere fibre curvature is also related to increased efficiency of mechanical dehairing of cashmere (McGregor and Butler, 2008a).

Differences in cashmere fibre curvature may reflect differences in cashmere breeding. Of more concern are the 9% of goats with fibre curvatures of <45°/mm. Previous research has shown that cashmere visually classified as "cashgora" has had a fibre curvature of <45°/mm (McGregor, 2000). Much of this so called "cashgora" may in fact be cashmere with a MFD between 17.5 and 20.0 μm that has a low fibre curvature and was not an assemblage of guard hair, intermediate hairs and down fibres (three fibre types) that is the usual definition of cashgora (Anon., 1997). Cashmere with a low fibre crimp frequency is viewed with some suspicion within the market (Anon., 1997). This view is mistaken to the extent that nutrition can markedly influence cashmere fibre curvature between 70 and 45°/mm (McGregor, 2003). Thus it has been argued that if low curvature cashmere meets all other industry specifications it should be acceptable as cashmere and will in fact be softer and more compressible than more traditional cashmere with higher fibre curvature (McGregor, 2000, 2004). As softness is regarded as the main commercial attribute of cashmere, low fibre curvature cashmere should be regarded as having a superior performance in this attribute.

Cashmere from does was 0.65 μm finer than cashmere from the bucks available for this study. Caution is needed in interpreting these data as the number of bucks and castrates available were limited. As bucks and castrates make up a small proportion of goats in the total flock, their contribution to the annual harvest of cashmere is small. However, it is essential to identify and use fine and productive cashmere bucks for breeding.

The amount of cashmere production from a relatively small sample of goats in two districts (Alay and Chong Alay, Osh Oblast) showed a mean combed cashmere production of 164 g per goat and a median clean cashmere production of 110 g. These values are similar to other unimproved native goats producing cashmere, but are only about one half of that produced by typical improved goats in cashmere producing regions and only one third of the production of goats on improved breeding farms in Inner Mongolia (Millar, 1986; Koul et al., 1990; Misra et al., 1998; Zhou et al., 2003; McGregor and Butler, 2008b).

Dmitriev and Ernst (1989) recorded data on the Don–Kyrgyz cross adult females which had down MFD of 16.6 μm and a harvest of 360 g. Adult males had coarser down with a MFD of 18.1 μm and 550 g harvest. While the Don goat breed was not maintained in a pure form after the state farms were dissolved in the mid 1990s, farmers have still been buying and crossing this type with their native cashmere goats, as the Don–Kyrgyz cross produces much more down which brings a higher total sale amount as Kyrgyz farmers sell down by weight rather than quality. Descendents of the original Don–Kyrgyz crosses have now spread in some areas of Naryn province, where goats were sampled in the present study. However, the Don–Kyrgyz crosses were not generally successful in the far southern districts of Osh province, where goats were sampled in the present study.

The weight of cashmere combed from goats was greater in higher altitude villages, but this is probably due to the sampling being undertaken at the lower altitude villages during late April, when a proportion of the goats had lost some of their cashmere.

4.2. Development implications

There are farmers and cashmere goats in the sampled districts of Kyrgyzstan which produce the finest qualities of cashmere. Cashmere from these five districts in two Oblasts (provinces) of Kyrgyzstan satisfies the most important characteristics of internationally traded cashmere in the commercial sphere. The vast majority of these samples are fine, have low variation in fibre diameter and have fibre curvature (crimping) typical of Chinese and Mongolian cashmere, which is the world standard for best quality (McGregor, 2000, 2003, 2004).

Most of the cashmere was coloured and would be discounted at least 25% compared with similar qualities of white cashmere, for example from Chinese goats. While there may have been a statistical effect of the colour of cashmere on MFD once age and sex of goat and farmer was taken into account there were insufficient of these coloured samples to provide a meaningful conclusion. If further testing demonstrated that these colours had a different MFD to white and coloured cashmere the commercial significance of such a finding could only be determined when the measurements of MFD were combined with total cashmere weight and cashmere price before conclusions can be made regarding the favouring of one colour over another. Colour of goats also has adaptive and social significance beyond that of market preferences.

Cashmere from 1-year-old goats is finer and therefore should be kept separate after harvesting, and not mixed with cashmere from other age groups. Fine cashmere was also produced by older goats and if this can be separated before packaging and placed with other fine cashmere then financial returns for farmers could be improved. Cashmere from the farmers with the finest cashmere, and cashmere from farmers with the coarsest cashmere should be kept separate from the average cashmere.

The results show that cashmere production has the potential to provide important income for Kyrgyz pastoral farmers. However, some farmers, villages and districts have better cashmere goats than others. It is therefore very important to encourage the farmers producing the coarsest cashmere to obtain fine cashmere bucks. As a first practical step, there need to be changes in the way farmers select breeding bucks and does (females), for those farmers producing the coarsest and therefore least valuable cashmere. These farmers need training in the identification of the finest cashmere bucks, perhaps provision of fine and productive bucks and more information on commercial prices for better quality cashmere, to motivate them to select the best bucks. Where the cashmere was coarser in the districts of Atbashy, Jumgal and Naryn, in Naryn Oblast, and for some farmers in Osh Oblast, it is quite likely that this is a consequence of the use of Don–Kyrgyz crossbred goats.

In response to these findings the Aga Khan Foundation Mountain Societies Development Support Programme Kyrgyzstan is following up with further training of farmers on cashmere sorting. The Kyrgyz Cashmere Producers' Association has liaised with several international cashmere buyers and publicised the research results (http://www.newag.info/09/03/focuson/focuson3.php). A private, non-profit research foundation based in Osh, called "Kyrgyz Cashmere Producers' Association" was established in 2008. The group has selected goats from 13 villages in which farmers' sampled flocks had the finest cashmere test results (<15.5 μm). These goats are being kept in a mountain village in Alay district by one of the trained cashmere collectors. They are monitored for their reproductive performance and fibre traits. By 2010 the best selected bucks from this flock will be offered for sale to local farmers, and income re-invested in the flock.

There needs to be an assessment of how farmers select breeding males (bucks) for their flocks, and advice given to farmers that they should avoid retaining breeding males with cashmere coarser than 18 μm. For improvement in both production of meat and fine cashmere, more evaluation of the production of bucks is needed. Culling (selling or slaughtering) of goats should be done on goats that produce the coarsest cashmere, the least amount of cashmere and the least number of kids. The results of this analysis indicate that from the age of 5 years, the coarsest female goats should be carefully evaluated. Farmers should be trained about the relationship between cashmere crimp (fibre curvature) and MFD for both buck selection practices and for preparing cashmere for sale. These are visual characteristics that can be easily observed after farmers receive simple training.

The relationship between altitude and cashmere production needs to be examined further to investigate if altitude has any real effects on cashmere production.

There is substantial scope for significant improvement in cashmere production and the potential improvement is illustrated by the observation that there were goats present that produced >300 g of combed cashmere, with sufficient fineness for commercial purposes. What is needed is a production system that ensures that all goats can produce over 300 g each year of fine cashmere and that this fibre is harvested and not lost. Selection of bucks for breeding purposes should include: greater cashmere weight; finer cashmere; white colour; longer cashmere fibre; greater fibre curvature.

5. Conclusions

There are farmers and cashmere goats in all districts of Kyrgyzstan which produce the finest qualities of commercial cashmere. There is substantial scope to increase the production and commercial value of cashmere produced by Kyrgyz goats. There are also villages and farmers that need to change their buck selection practices if they wish to sell acceptable cashmere.

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Appendix A. The mean, standard deviation and range in measured attributes of cashmere

For the measured attributes of cashmere the mean, standard deviation, maximum and minimum values are set out for different age classes (Table A1), different colours of cashmere (Table A2), from goats of different sex (Table A3) and from different districts of Kyrgyzstan (Table A4).

Table A1
Mean, standard deviation (SD) and range in measured attributes of cashmere from goats of different ages.

Attribute	Mean	SD	Minimum	Maximum	*n*
Mean fibre diameter (μm)					
1 year of age	15.4	1.31	12.6	20.8	133
2 years of age	16.1	1.38	12.8	20.5	182
3 years of age	16.4	1.20	13.0	20.4	181
4 years of age	16.4	1.33	13.3	20.4	113
5 years of age	16.8	1.13	14.5	19.5	72
6 years of age	16.8	1.24	13.8	19.5	50
7 years of age	16.7	1.37	13.7	18.8	21
8 years of age	17.4	0.98	16.4	18.6	4
Fibre diameter SD (μm)					
1 year of age	3.08	0.365	2.32	4.48	
2 years of age	3.13	0.340	2.26	3.97	
3 years of age	3.09	0.327	2.32	3.98	
4 years of age	3.09	0.347	2.44	4.07	
5 years of age	3.15	0.321	2.47	3.92	
6 years of age	3.13	0.330	2.50	4.13	
7 years of age	3.13	0.199	2.67	3.64	
8 years of age	3.22	0.265	2.95	3.53	
Coefficient of variation of fibre diameter (%)					
1 year of age	20.0	1.92	16.0	25.6	
2 years of age	19.5	2.12	13.6	24.5	
3 years of age	18.9	2.16	14.3	25.2	
4 years of age	18.9	2.35	13.3	27.1	
5 years of age	18.8	2.22	14.3	24.2	
6 years of age	18.7	2.27	13.7	25.1	
7 years of age	18.8	1.48	16.6	21.9	
8 years of age	18.6	2.08	16.7	21.5	

Table A1 (*Continued*)

Attribute	Mean	SD	Minimum	Maximum	*n*
Fibre curvature (°/mm)					
1 year of age	60.6	9.58	40.7	93.4	
2 years of age	57.6	10.09	31.8	87.8	
3 years of age	57.1	9.47	33.6	99.6	
4 years of age	57.0	9.34	34.2	90.2	
5 years of age	56.2	9.04	37.4	78.7	
6 years of age	55.2	9.85	37.7	79.1	
7 years of age	57.4	2.45	42.3	80.5	
8 years of age	53.5	2.94	49.6	56.7	

Table A2
Mean, standard deviation (SD) and range in measured attributes of cashmere from goats of different cashmere colours.

Attribute	Mean	SD	Minimum	Maximum	*n*
Mean fibre diameter (μm)					
Black	16.3	1.33	12.6	20.8	476
Blue	16.9	0.97	15.0	18.5	17
Brown	16.4	1.46	15.1	19.5	7
Grey	16.1	1.31	13.7	19.1	53
Red	14.3	0.79	13.0	15.2	8
White	16.2	1.46	13.0	20.5	147
Yellow	15.9	1.37	13.0	18.6	48
Fibre diameter SD (μm)					
Black	3.17	0.325	2.32	4.48	
Blue	3.27	0.310	2.75	3.69	
Brown	3.11	0.292	2.78	3.65	
Grey	2.99	0.294	2.39	3.63	
Red	2.71	0.213	2.55	3.21	
White	3.03	0.349	2.26	3.97	
Yellow	2.84	0.224	2.44	3.30	
Coefficient of variation of fibre diameter (%)					
Black	19.5	2.16	13.3	27.1	
Blue	19.4	2.09	15.5	22.4	
Brown	19.0	2.33	14.8	22.4	
Grey	18.6	1.65	14.8	21.7	
Red	19.0	1.50	16.9	21.9	
White	18.8	2.28	13.6	25.1	
Yellow	18.0	1.85	14.5	22.1	
Fibre curvature (°/mm)					
Black	57.8	9.53	33.6	93.4	
Blue	53.9	6.60	42.4	67.8	
Brown	55.9	8.23	40.4	64.7	
Grey	56.2	9.36	37.7	80.5	
Red	69.6	4.58	63.6	77.1	
White	57.5	10.73	31.8	99.6	
Yellow	57.6	9.56	39.1	90.2	

Table A3
Mean, standard deviation (SD) and range in measured attributes of cashmere from goats of different sex.

Attribute	Mean	SD	Minimum	Maximum	*n*
Mean fibre diameter (μm)					
Doe	16.2	1.34	12.6	16.3	719
Buck	16.3	1.79	12.8	20.8	35
Castrate	16.0	0.69	14.7	16.6	6
Fibre diameter SD (μm)					
Doe	3.10	0.332	2.26	4.13	
Buck	3.19	0.378	2.63	4.48	
Castrate	3.36	0.466	2.92	4.06	
Coefficient of variation of fibre diameter (%)					
Doe	19.2	2.19	13.3	27.1	
Buck	19.6	1.76	14.3	22.9	
Castrate	21.0	2.53	18.4	24.8	

Table A3 (*Continued*)

Attribute	Mean	SD	Minimum	Maximum	*n*
Fibre curvature (°/mm)					
Doe	57.3	9.66	31.8	99.6	
Buck	63.5	9.33	43.6	92.7	
Castrate	62.3	7.53	55.1	75.4	

Table A4
Mean, standard deviation (SD) and range in measured attributes of cashmere from different districts of Kyrgyzstan.

Attribute	Mean	SD	Minimum	Maximum	*n*
Mean fibre diameter (μm)					
Alay	15.8	1.26	13.0	19.1	260
Atbashy	16.7	1.05	14.4	19.6	108
Chong Alay	15.5	1.36	13.0	20.0	68
Jumgal	16.7	1.32	13.0	20.5	162
Naryn	16.4	1.40	12.6	20.8	162
Fibre diameter SD (μm)					
Alay	2.93	0.277	2.32	3.77	
Atbashy	3.26	0.290	2.54	4.13	
Chong Alay	2.95	0.306	2.26	3.49	
Jumgal	3.17	0.308	2.32	4.06	
Naryn	3.29	0.324	2.54	4.48	
Coefficient of variation of fibre diameter (%)					
Alay	18.6	1.92	14.0	23.3	
Atbashy	19.6	2.05	14.9	25.1	
Chong Alay	19.0	1.98	13.3	24.1	
Jumgal	19.1	2.18	13.6	25.0	
Naryn	20.1	2.41	14.3	27.1	
Fibre curvature (°/mm)					
Alay	59.9	9.08	37.7	87.2	
Atbashy	56.8	7.54	35.9	78.7	
Chong Alay	59.8	11.9	34.2	99.6	
Jumgal	54.1	9.53	31.8	93.4	
Naryn	57.2	10.07	35.7	92.7	

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