Mongolian Journal of Agricultural Sciences, Vol 15 No 36 (2022)
https://doi.org/10.5564/mjas.v15i36.2446

Study on distinct quality properties of cashmere from local goat breeds of Mongolia

Mandakh Begzjav[1], Enkhtuya Dorj[2], Bolormaa Vanchigdorj[3], Enkh-Amgalan Tseelei[4*], Altantsetseg Duger[5]

[1]Institute for Extension of Advanced Agricultural Technology, Building 8, 1-4 Khan Uul District, 17042, Ulaanbaatar, Mongolia
[2]Mongolian University of Science and Technology, Baga toiruu 34, Sukhbaatar district, 14191 Ulaanbaatar, Mongolia
[3]Ministry of Food Agticulture and Light Industry, Government Building 9, Peace Avenue 16a, Bayanzukh district, 13381, Ulaanbaatar, Mongolia
[4]Mongolian National Federation of Pasture User Groups of Herders, Tokyo tower, 26, 6-606, Bayanzurkh district, 13380, Ulaanbaatar, Mongolia
[5]Mongolian Wool and Cashmere Association, Chinggis Avenue, Building Arig Gal, Khan uul district, 17040, Ulaanbaatar, Mongolia

https://orcid.org/0000-0002-3621-8218

*Corresponding author: tsenkhamgalan@gmail.com

Received: 03.06.2022 Revised: 15.11.2022 Accepted: 18.11.2022

Abstract

The research was carried out in 2021 to determine the specific quality properties of local Mongolian breeds of cashmere goats. The research covered 122 herder households from 13 soums in 8 aimags. A total of 4,560 samples were collected from 1,522 goats representing the main factors determining cashmere quality: ecological habitat, various herd management practices, local breeds, age and sex of goats, and cashmere colour. Cashmere fibre diameter (FD), fibre curvature (FC), and coefficient of variation of fibre diameter (CVFD) were tested in 1,522 samples, and cashmere length was tested in 1,387 samples. The overall mean fibre diameter (MFD) was 16.1 µm, mean length (FL) was 44.9 mm, and fibre curvature (FC) was 61.9°/mm. Cashmere from one-year-old goats was significantly finer than cashmere from older goats (about 1.0 µm, $P<0.05$). Cashmere from does in the samples tested was significantly finer than cashmere from the bucks. Over the range in mean fibre diameter, from 13.5 to 19.0 µm, fibre curvature declined from 87.8 to 44.2°/mm. Of all cashmere samples, 40.6% belonged to super fine (≤15.5µm), 43.7% and 12.1% had a fibre diameter between 15.51-16.80 and 16.81-17.50 µm, respectively, and were suitable for knitwear. Only 3.6% of samples tested were between 17.51 to 19.00 µm and may only be suitable for weaving. The average CVFD values of cashmere of Mongolian breeds of cashmere goats was 22.5 ± 0.04%, with an individual range of 17.0-26.9%. This shows that it has lesser variation than Alashan white cashmere goats of Inner Mongolia Autonomous Region, China, where CVFD ranged from 27.09% to 41.39%. Compared to cashmere from China, Tajikistan, and Kyrgyzstan, with mean fibre curvature of 46, 46, and 58mm, respectively, the cashmere of local Mongolian breeds of goats would be considered curvier and longer, which makes stronger yarns. Short, higher crimped, softer cashmere may be preferred for woollen-spun yarns, but longer, lower crimped, softer cashmere may be preferred for woven yarn destined for knitwear. Fibre curvature of Mongolian cashmere goats declined an average of 6.1°/mm for a 1µm 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. Significant differences were found between the cashmere of local Mongolian breeds of goats kept in open, natural rangelands and herded in a nomadic way in distinct ecological conditions of harsh continental climate compared to those breeds of goats kept in intensive farming. This shows the potential to offer distinct quality cashmere from local Mongolian breeds while maintaining proper management and selective breeding.

Key words: fibre diameter, length, curvature, relationship

Introduction

By the end of 2021, of the 26.5 million goats in Mongolia, 25.5 million are belong to cashmere producing, and the remaining goats are cashgora and their crossbreeds [1]. For centuries, Mongolian nomadic herders have selectively bred several local breeds of cashmere for their resistance to Mongolia'sharsh continental climatic conditions and the quality of their cashmere. Goats are herded in open access natural grasslands, and herder householdsrotate between four seasonal rangelands, making sure that animals have access to fresh grass and water. Goat herd management practices vary between ecological regions, as each geographical locationhasits own specific micro-climate conditions, seasonal rangeland productivity, yearly rainfall, and access to minerals and nutrition. Goats are very active foragers, covering a wide area in search of scarce plant materials. A goat's small mouth, narrow muzzle, and split upper lip enable them to pick small leaves, flowers, fruits, and other plant parts, thus choosing only the most nutritious available feed. As natural browsers, given the opportunity, goats will select over 60% of their daily diet from brush and woody perennials. In a pasture situation, goats tend to graze from the top to the bottom of plants and do not like to graze near the soil surface. Therefore, goats will more uniformly graze a canopy than other ruminants. Goats prefer not to change their grasslands often; they feel comfortable if they have regular, seasonal grazing routes. Goats in Mongolia are raised in desert rangelands with small bushes and steppe grassesand are known to be more efficient rangeland users. Local goat breeds are used to the low-producing yet nutritious grasses of Mongolia's dryland ecosystems [2].

Mongolia's pastoral goat population is a living factory that produces valuable fine fibre, meat, and milk from pastureland grazing. Mongolian grassland is classified into approximately 100 types, and more than 2,000 varieties of plants provide nutrients onthese different pasturelands. The nutrient quality of over 550 plants is excellent for livestock nutrition [3].

There are four categories of cashmere in Mongolia: superfine (≤15.5 μm), first grade (15.51-16.80 μm), second grade (16.81-17.50 μm), and third grade (17.51-19.00 μm). The price of cashmere in some countries is closely associated with fibre quality. In Mongolia, cashmere has gradually begun to be judged by fibre quality. Additionally, nucleus herds with fine fibre diameter have been established in some flocks. Therefore, it is also necessary to discuss fibre grade.

This paper studies cashmere quality attributes and variation in Mongolian breeds of cashmere goats bred in different natural and ecological zones to determine the scope of goat population improvement required.

Materials and Methods

Collection of cashmere samples

Samples were collected from randomly selected goats of each sex (does and bucks) by age (1 and ≤4 years); in total, 4,560 samples were collected from 1,522 goats representing eight different breeds of Mongolian cashmere goats bred by122 herder households in 13 locations (soums). Sampling was conducted in early spring (mid-March 2021), prior to the seasonal moult and regular annual cashmere harvesting period (Table 1). Geographical location of cashmere goat breeds covere in the study is shown in Fugure 1.

Samples were carefully selected from different body parts of cashmere goats; 30% were taken from the neck, 40% from the shoulder, and 30% from the hip. Samples were stored in sealed plastic bags labelled with identity tag number and breed, as well as the age and sex of the goat, with details about location and herder

Fibre testing

The raw cashmere samples consisting of undercoat and guard hair were analysed in Fibre Laboratory of Gobi Company, Ulaanbaatar city. For the analysis, each sample was manually dehaired, then was washed in solvent, dried, reconditioned, minicored into 2 mm snippets, and tested using an optical fibre diameter analyser (OFDA 4000 in the mode of an OFDA 100). Based on more than 8,000 individual fibre measurements, mean cashmere fibre diameter (MFD, μm), fibre curvature (FC, mm), and the coefficient of variation of fibre diameter (CVFD) were measured using a fibre diameter cut-off of 30 μm for cashmere.

Cashmere length (CL, mm) was obtained as the mean of three staples. For each staple, a suitable portion of the dehaired samples was sorted by length onto a velvet board, and cashmere staple length was obtained as the average of the maximum, minimum, and midpoint measures.

Table 1.

Geographic location of cashmere goat breeds covered by the study

	Breeds of Mongolian cashmere goats	**Abbr.**	**Aimag, soum**	**No. of goats**	**HH 1**	**No. of cashmere samples**
1	Zavkhan Buural	ZB	Zavkhan, Durvuljin	117	12	351
2	Erchim black	EB	KHuvsgul, Tumurbulag	118	9	354
3	Bayandelger red	BR	Sukhbaatar, Bayandelger	120	14	360
4	Altai red	AR	Khovd, Altai	118	9	354
5	Ulgii red	UR	Uvs, Ulgii	119	14	357
6	Zalaa-Edren white	ZW	Bayankhongor, Bayan-Undur	117	8	351
7	Bumbugur red strain	BS	Bayankhongor, Bumbugur	116	8	348
8	Local Mongolian	L1	Dornod, Tsagaanovoo	120	15	360
9	Local Mongolian	L2	Dornod, Dashbalbar	119	14	357
10	Local Mongolian	L3	Gobi-Altai, Bugat	106	9	318
11	Local Mongolian	L4	Khuvsgul, Tsetserleg	118	9	354
12	Local Mongolian	L5	Sukhbaatar, Ongon	117	14	351
13	Local Mongolian	L6	Uvs, Sagil	115	10	345
	Total			**1,520**	**122**	**4,560**

Abbr. – abbreviation

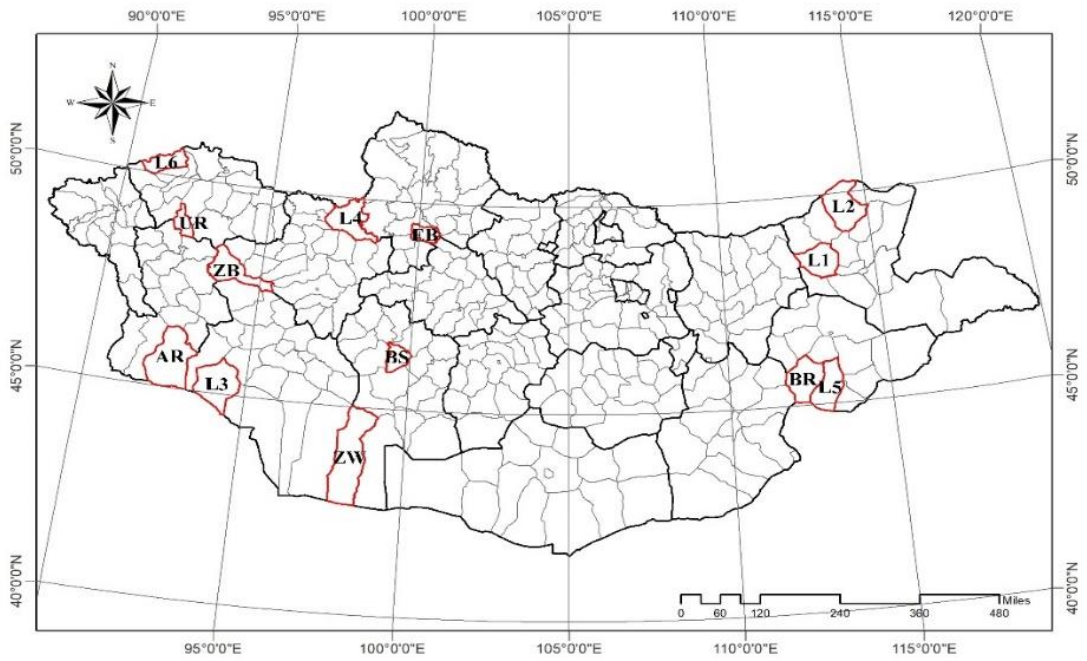

Figure 1. Geographical location of cashmere goat breeds covere in the study.

Statistical analysis

Mean and statistical differences between quantitative variables were analysed using a linear model. Sex, age, and breed of the goats were fitted as independent variables while fibre characteristics were set as dependent variables.

Results

Overall cashmere fibre attributes

The overall means and standard errors for the cashmere traits of all breeds ofcashmere goats in accordance with their age and sex is shown in Table 2. Mean fibre diameter (MFD) was16.1μm, length (FL) was 44.9 mm, and fibre curvature (FC) was 61.9°/mm. Cashmere from one-year-old goats was significantly finer than cashmere from older goats (about 1.0μm, P<0.05).

Table 2.

Overall means of fibre characteristics for Mongolian breeds of cashmere goats

Factors	Categories	No. of goats	MFD, μm	Fibre curvature, °/mm	Fibre length, mm
Age	1 year of age	765	15.6±0.11[a]	61.6±0.95[a]	41.9±1.06[a]
	≥4 year of age	755	16.6±0.12[b]	62.2±1.06[a]	47.9±1.03[b]
Sex	Does	779	15.6±0.11[a]	60.6±1.08[a]	44.1±1.09[a]
	Bucks	741	16.2±0.12[b]	63.2±0.95[b]	45.7±0.95[b]
Overall		1520	16.1±0.11	61.9±1.07	44.9±1.05

Different letters indicate significant differences with P < 0.05.

The study indicated that the effect of sex was significant for thecashmere diameter, fibre curvature, and length of Mongolian cashmere goats. Cashmere diameter for bucks and does was 16.2 ± 0.12 and 15.6 ± 0.11μm; fibre curvature was 63.2±0.95 and 60.6±1.08°/mm; and the length of fibre was 45.7 ± 0.95 and 44.1 ± 1.09mm, respectively. Increases in fibre length and curvature in goats of four or more years of age also occurred according to age and sex. Bucks had longer fibre length and more curvature than does.

Fibre diameter

Within the Mongolian breeds of cashmere goats, mean fibre diameter in goats aged 1 to 4 or more years ranged from 15.4 to 16.9 μm for does and from 14.9 to 17.9 μm for bucks, coarsening by 1.5 to 3 microns with age, depending on the breed. Cashmere FD averaged 15.5 -16.5 μm between breeds. Erchim black cashmere goats with MFD of 16.5 μm had the coarsest fibre, and Altai red had the finest cashmere with 15.5 μm. The overall mean fibre diameter for Altai red, Zalaa-Edren white, Zavkhan Buural, and Bumbugur red strain ranged from 15.5 to 16.5; whereas, Bayandelger red, Ulgii red, local Mongolian, and Erchim black ranged from 16.0 to 16.5 μm (Table 3).

In accordance with the National standard for raw goat fibre [4], 40.6% of all cashmere samples belonged to superfine (≤15.5 μm), 43.7 and 12.1% had a fibre diameter between 15.51–16.80 and 16.81–17.50 μm, respectively, and were suitable for knitwear. Only 3.6% of samples tested were between 17.51 to 19.00 μm, may only be suitable for weaving (Table 4).

Table 3.
Mean fibre diameter (MFD), fibre curvature (FC) and fibre length (FL) in different Mongolian cashmere goat breed categories

Breeds of cashmere goats	Age	Sex	No. of goats	MFD, μm	Fibre curvature, °/mm	Fibrelength, mm
Local Mongolian	1yr	F	199	15.7±0.1	60.1±1.0	42.2±1.1
		M	154	16.2±0.1	59.9±1.0	42.3±1.1
	≥4 yrs	F	171	16.4±0.1	59.7±0.9	46.8±0.9
		M	171	17.2±0.1	62.9±1.1	49.7±0.9
	Subtotal		695	16.3±0.1	60.6±1.0	45.9±1.0
Zavkhan Buural	1yr	F	28	15.5±0.1	64.1±0.8	41.9±1.0
		M	30	15.1±0.1	65.2±1.0	41.1±0.8
	≥4yrs	F	29	16.1±0.1	62.3±0.9	43.8±1.1
		M	30	16.3±0.2	67.3±1.0	41.7±0.5
	Subtotal		117	15.8±0.1	64.7±0.9	43.5±0,6
Erchim black	1yr	F	28	15.5±0.2	58.6±0.9	41.9±1.0
		M	30	15.7±0.1	59.9±1.0	42.7±0.8
	≥4yrs	F	30	16.9±0.2	57.7±0.9	42.5±1.1
		M	30	17.9±0.3	57.8±1.1	49.6±0.5
	Subtotal		118	16.5±0.1	58.5±1.0	44.2±0.6
Bayandelger red	1yr	F	30	15.5±0.1	67.0±1.2	40.7±0.6
		M	30	14.9±0.2	62.8±0.7	34.9±0.8
	≥4yrs	F	30	16.7±0.2	57.2±0.9	43.4±0.7
		M	30	17.1±0.2	60.4±1.1	51.9±1.9
	Subtotal		120	16.0±0.1	59.4±0.8	42.7±0.5
Altai red	1yr	F	30	15.4±0.2	67.0±1.3	53.4±1.6
		M	30	14.9±0.1	69.1±1.1	50.1±2.1
	≥4yrs	F	30	15.8±0.1	63.8±1.1	56.9±1.6
		M	28	15.9±0.2	69.2±1.2	61.8±2.0
	Subtotal		118	15.5±0.1	67.3±1.1	53.3±1.4
Ulgii red	1yr	F	30	15.9±0.2	62.1±0.9	43.7±0.9
		M	30	15.2±0.1	65.8±1.1	44.3±0.2
	≥4yrs	F	30	16.7±0.1	61.4±0.8	47.5±1.1
		M	29	16.7±0.1	66.8±0.7	53.2±1.3
	Subtotal		119	16.1±0.1	64.0±0.8	47.1±0.6
Zalaa-Edren white	1yr	F	30	15.7±0.2	61.6±1.1	40.2±0.9
		M	30	15.1±0.2	66.9±1.1	36.6±1.0
	≥4yrs	F	27	16.1±0.2	61.7±1.2	41.4±1.0
		M	30	15.4±0.2	65.6±1.2	43.1±0.8
	Subtotal		117	15.6±0.2	64.0±1.1	40.3±0.5
Bumbugur red strain	1yr	F	27	15.8±0.1	57.7±0.7	35.9±0.8
		M	29	15.5±0.2	63.8±1.0	37.9±1.1
	≥4yrs	F	30	15.7±0.2	62.0±1.0	39.4±0.8
		M	30	16.2±0.2	65.9±0.5	42.6±0.9
	Subtotal		116	15.8±0.02	62.5±0.6	39.0±0.7

Table 4.

Distribution of fibre diameters of samples according to cashmere grade

Cashmere grade	Superfine (≤15.5 μm)	1st grade (15.51-16.80 μm)	2nd grade (16.81-17.50 μm)	3rd grade (17.51-19.00 μm)
Distribution, %	40.6	43.7	12.1	3.6

Softness

The "handle" of a textile product is generally referred to as "softness", and can be evaluated using easily obtained measurements of fibre diameter distribution. As shown in Table 5, the coefficient of variation for fibre diameter was 22.5 ± 0.04% with an individual range of 17.0-26.9%. Cashmere samples with a coefficient of variability up to ≤24% of the diameter of cashmere fibres accounted for 88.9% of all samples.

Table 5.

Overall means, standard deviations (SD), and ranges of the coefficient of variation for fibre diameter (CVFD)

Parameter	No. of samples	Mean	SD	Min.	Max.
CVFD	1520	22.5±0.04	1.73	17.0	26.9

Fibre curvature

All samples had a curvature greater than 44.2/mm, with 45.6% between 44.2 and 60/mm; 55% were between 61 and 75°/mm; and 2.4% were between 76 and 88°/mm. On average cashmere from bucks had significantly 2.6°/mm more curvature than does. Age did not have any effect on fibre curvature (Table 2). Mean fibre curvature of Mongolian cashmere samples ranged from 60.6 for local breed to 67.3°/mm for Altai red cashmere goats (Table 3).

Fibre length

Average cashmere length was 44.9 mm (Table 2) with a range of 39.4–53.3 mm between breeds (Table 3). Altai red goats with cashmere length of 55.3 mm had the longest, and Bumbugur red strain had the shortest lengthwith 39.4 mm. Cashmere from four ormore year-old goats was significantly longer than cashmere from one-year-old goats (about 1.6 mm, $P<0.05$), and males also had longer cashmere than females (about 6.0 mm, $P<0.05$). Among all the samples, 49.3% had cashmere length between 40 and 50 mm, 31% was shorter than 40 mm, and 19.7% was longer than 50 mm. As cashmere longer than 34-36 mm is used for worsted spinning [5], the results indicate that the majority of cashmere of goats would qualify for the worsted and semi-worsted industry.

Relationship between cashmere fibre quality attributes

A significantly strong negative relationship was found between mean fibre diameter and fibre curvature (−0.459, $P < 0.0001$). The actual distribution of fibre curvature and FD of the samples is shown in Figure 2. An increase inthe mean fibre diameter of cashmere was associated with a decline in cashmere fibre curvature. Over the range in mean fibre diameter, from 13.5 to 20.7 μm, fibre curvature declined from 87.8 to 44.2°/mm. In other words, as cashmere becomes coarser, it has less fibre crimping.

Average cashmere fibre length was 44.9 mm (Table 2) with significant age and sex effects. As cashmere longer than 34-36 mm is used for worsted spinning [6], the results indicate that all samples of cashmere of Mongolian goat breeds would qualify for the worsted and semi-worsted industry. The actual distribution of cashmere length and FD of samples in Figure 3 shows that there is no strong relationship between these two characteristics. Thus, a substantial proportion of the samples with a fibre diameter below 16.5 μm had a fibre length above the average of 45 mm.

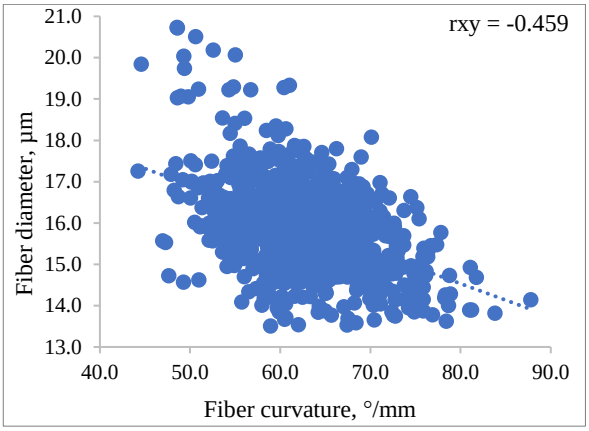

Figure 2. The relationship between mean fiber diameter and fiber curvature

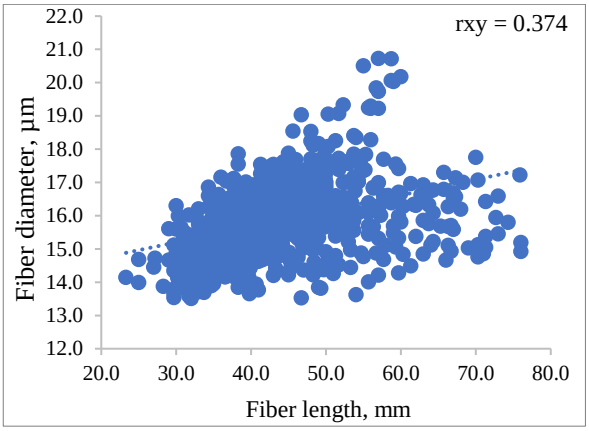

Figure 3. The relatioship between mean fiber diameter and fiber length

Discussion

Breed effect was statistically significant for all traits of cashmere in Mongolian breeds of goats [2,7]. A large breed effect was also detected in other cashmere goats [8,9]. Our finding that older goats had coarser cashmere than yearling goats coincides with McGregor et al. [8], who also reported that younger goats of different regions of Osh and Naryn provinces of Kyrgyzstan and of the Pamir Mountain districts of Tajikistan had significantly lower MFD than older goats. The impact of age could be associated with larger body size, and reduced skin follicle density. Competition for nutrients enables the follicles to increase in size, resulting in increased fibre diameter in older goats.

Cashmere fibre is generally non-medullated and has a mean maximum diameter of 19 µm and the coefficient of variation around the mean should not exceed 24% [5]. The average CVFD values for Mongolian breeds of cashmere goats was 22.5 ± 0.04% with an individual range of 17.0–26.9 %, showing less variation compared to Alashan white cashmere goats of Inner Mongolia, China, where CVFD ranged from 27.09% to 41.39% [10]. Cashmere samples with a coefficient of variability up to ≤24% of the diameter of cashmere fibres accounted for 80.0-88.9% of all samples. This means that the uniformity of Mongolian goat cashmere fibre is quite good.

Higher cashmere fibre curvature is also related to increased efficiency of the mechanical dehairing of cashmere [5]. Differences in cashmere fibre curvature may reflect differences in cashmere breeding. Of more concern are goats with fibre curvatures of <45/mm.

Compared with cashmere of China, Tajikistan and Kyrgyzstan with mean fibre curvature of 46, 46 and 58°/mm [8,9], cashmere of local Mongolian breeds of goats would be considered highly curved and long, which makes stronger yarns. Short, higher crimped, softer cashmere may be preferred for woollen-spun yarns, but longer, lower crimped, softer cashmere may be preferred for woven yarn destined for knitwear. Fibre curvature of Mongolian cashmere goats declined an average of 6.1°/mm for a 1µm 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 [12].

A significantly strong negative relationship was found between mean fiber diameter and fiber curvature for Mongolian breeds of cashmere goats.

This negative relationship in cashmere goats from Kyrgyzstan and Australia was 51 and 39%, respectively [8]. Finer cashmere had higher fibre curvature than coarser cashmere in all these goats. As lower fibre curvature (crimp) can be easily observed, the association between fibre diameter and curvature can be used subjectively for the classing of cashmere in the field. This criterion is of significant commercial importance as cashmere buyers make purchase decisions based on fibre curvature to assess FD and acceptability and the efficiency of mechanical dehairing [11].

Conclusion

There is substantial scope for increasing the commercial value of cashmere produced by Mongolian goat breeds, particularly by increasing length for fine cashmere, reducing mean fiber diameter for the longest cashmere, and ensuring that cashmere has an acceptable fiber curvature and a different color. Significant differences were found between Mongolian goats and breeds compared to those intensively farmed or herded in other countries, indicating the potential to further improve Mongolian cashmere quality and the need for adopting proper management and selection methods through the selection of goats with finer cashmere, taking care of maintaining the excellent cashmere softness and curvature. fiber curvature and a different color. Significant differences were found between Mongolian goats and breeds compared to those intensively farmed or herded in other countries, indicating the potential to further improve Mongolian cashmere quality and the need for adopting proper management and selection methods through the selection of goats with finer cashmere, taking care of maintaining the excellent cashmere softness and curvature.

Conflict of Interests

The authors declare no conflict of interests.

Authors' Contribution

M.B., E.D., B.V., E.Ts. designed and performed the study; E.Ts. supervised the experiment; E.D., B.V., A.D. analysed data; all authors discussed the results and contributed to the final manuscript.

Acknowledgment

This research has been carried out with a financial support from the Green Gold Animal Health Project of the Swiss Agency for Development and Cooperation in Mongolia, and Step Eco Lab Project of the European Union.

References

[1] National Statistical Office of Mongolia, "Agricultural Sector." Government of Mongolia, (2022), [Online]. Available: http://1212.mn/stat.aspx?LIST_ID=976_L10_1

[2] Mandakh et.al. (2011) Goat Research for 50th Anniversary. Research Institute of Animal Husbandry.130-133.

[3] Tumurjav M. (2004). Mongolian pastoral livestock husbandry. (In Mongolian). 36-38

[4] Mongolian Agency for Standardization and Metrology, (2008) "MNS: National Standard for goat raw fiber."

[5] World Textile Publications (2010). 27, 623-627

[6] Anonymous. (1997). Guide to Clip Preparation. Cashmere Australia 19 (1), 1–23.

[7] Nadmid N., Mandakh B., and Dorjbat Yo. (2012) Goat Production. (In Mongolian). 114-165

[8] McGregor, B.A., Kerven, C., Toigonbaev, S. (2009). Sources of variation contributing to production and quality attributes of Kyrgyz cashmere in Osh and Naryn provinces: Implications for industry development. Small Ruminant Research. 84, 89-99. https://doi.org/10.1016/j.smallrumres.2009.06.008.

[9] McGregor, B.A., Kerven, C., Toigonbaev, S. (2011). Sources of variation affecting cashmere grown in the Pamir Mountain districts of Tajikistan and implications for industry development. Small Ruminant Research. 99, 7-15.https://doi.org/10.1016/j.smallrumres.2011.01.018

[10] Stefano Pallottiaetal. (2018). Variability of fibre quality on Chinese Alashan Left Banner white cashmere goat. Italian Journal of Animal Sciences, Vol.17, 1, 53-56. https://doi.org/10.1080/1828051X.2017.1350121

[11] McGregor, B.A., Butler, K.L. (2008). The effects of cashmere attributes on the efficiency of dehairing and dehaired cashmere length. Text. Res. J.78, 486-496. https://doi.org/10.1177/0040517507087679

[12] McGregor, B.A. (2007). Cashmere fibre crimp, crimp form and fibre curvature. International Journal of Sheep and Wool Science 55 (1): 105-129