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The relationship between fiber diameter and performance of yak wool

Baigalmaa Danzan[1*], Sereeterdorj Dugerragchaa[2], Naransolongo Ukhnaa[3], Khishigjargal Tsedev[4]

[1] Graduate School, Mongolian University of Life Sciences, Zaisan 17024, Ulaanbaatar, Mongolia
[2] School of Fine Arts and Technology, Mongolian National University of Education, Baga toiruu 14191, Ulaanbaatar, Mongolia
[3] School of Finance and Economics, Ikh Zasag International University, Ikh zasag II campus, Ulaanbaatar, Mongolia
[4] School of Animal Science and Biotechnology, Mongolian University of Life Sciences, Zaisan 17024, Ulaanbaatar, Mongolia

*Corresponding author: baigalmaa@muls.edu.mn

https://orcid.org/0000-0001-7845-2830

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Abstract

This article demonstrates the thermal sensitivity and conductivity as well as the water permeability and absorptivity of Mongolian yak wool surfaces according to the Kawabata evaluation method. According to the results of the study, the mean value of thermal sensitivity (Qmax) of yak wool surface is 0.051 w/cm^2 for down and 0.061 w/cm^2 for coarse hair while the mean value of thermal conductivity is 2.08x10^{-4} (cal/cm ·^{0}C) for down and 2.63x10^{-4}(cal/cm · ^{0}C) for coarse hair.
This study, with its high level of confidence (p = 0.05), proves the difference between down and coarse hair. Additionally, the study shows a strong correlation between the thermal conductivity and the fiber diameter of Mongolian yak wool, resulting in a correlation level of r = -0.80 for down and r = 0.86 for coarse hair.
When measuring the wettability of Mongolian yak wool, yak wool surface exhibited waterproof properties with a contact angle of 146.50 degrees for down hair and a contact angle of 147.10 degrees for coarse hair. The study also revealed a low correlation level of r = 0.39 for down and r = 0.40 for coarse hair when examining the relationship between the contact angle and the diameter of yak wool.

Keywords: thermal sensitivity, thermal conductivity, water permeability, water absorptivity, fiber diameter

Introduction

The heat retention process that takes place between the yak's skin layer and hair cover is very complex. Heat emitted from the yak's body is transferred to its hair cover via sweat and moisture. The yak's hair consists of breathable fibers that help create a microenvironment between the skin layer and hair cover. This microenvironment hosts and regulates the air exchange and heat transfer, which allows the yak to retain its heat in cold climates and maintain its thermal balance from physiological functions. According to the variability study, the ideal living conditions for a yak consist of the microenvironment having a surface skin temperature of 32 ± 1 degrees Celsius with a humidity level of 50 ± 10 percent. In studies, it was also noted that the hair cover plays a significant role in creating and maintaining this environment [1-5]. In order to manufacture quality products that meet hygienic standards, there have been several studies conducted in recent years on utilizing this quality of animal hair and examining the microenvironment created between the human body and the material of their clothing . As a result, the properties of fibrous materials, such as thermal sensitivity, heat retention, sweat moisture and viscosity, water permeability and absorptivity are taken into consideration [6]. The heat retention of clothing is its ability to reduce the loss of heat emitted from the human body when the ambient temperature is lower than the human body temperature [7-9]. The thermal sensitivity refers to the sensation in the human body under the influence of heat flux when clothes made of textiles or other materials come in contact with the human skin [10-13]. This feature has recently become one of the major reasons that impact the sales of underwear, shirts, gloves and jackets. Therefore, there exists an urgent requirement to conduct a detailed study on the performances of Mongolian yak wool.

Materials and methodology

Following the Kawabata evaluation method, we prepared yak wool samples and examined the thermal conductivity and thermal sensitivity of yak wool surface fibers at the Fashion and Material Laboratory at Seoul University. We prepared yak wool samples in accordance to ISO 17751 and studied the water absorptivity of down at Nano Study Laboratory of National University of Mongolia. We analyzed the quantitative data using the Descriptive Statistic Covariance and Correlation subprogram of the Data analysis program.

Results

Using the methodology mentioned above, we determined the thermal sensitivity (Qmax), thermal conductivity, and water absorptivity of yak wool surface fibers on each of the four colors. The quantitative measurement values were extracted from the Descriptive Statistic Covariance subprogram of the Data analysis program. Tables 1-5 provided below show our statistical outcomes.

Table 1

Thermal sensitivity of yak wool, (n=10)

Specimens	Colors	Average, (w/cm^2)
Down	White	0.051±0.001
	Light blue, gray	0.046±0.001
	Brown	0.049±0.001
	Dark	0.052±0.001
	Average	0.051
Coarse hair	White	0.061±0.001
	Light blue, gray	0.060±0.001
	Brown	0.058±0.001
	Dark	0.059±0.001
	Average	0.061

With a high confidence level (p = 0.05), Table 1 shows the coefficients of thermal sensitivity having variability among the four colors for yak down while having consistency among the four colors for coarse hair.

Table 2

Statistical outcomes of yak wool thermal conductivity (n=10)

Specimens	Color	K±k x10^{-4}(cal/cm·^{0}C)
Down	1	2.7±0.06
	2	2.20±0.05
	3	1.60±0.04
	4	1.80±0.03
	Average	2.08±0.04
Coarse hair	1	3.50±0.09
	2	2.80±0.06
	3	2.00±0.06
	4	2.20±0.06
	Average	2.63±0.07

Table 2 shows that the average thermal conductivity of yak wool is 2.08 (x10^{-4} (cal/cm ^{0}C) for down and 2.63 (x10^{-4} (cal/cm ^{0}C) for coarse hair. The thermal conductivity of yak wool results are compared in table 3 below.

Table 3

Relationship between fiber diameter and thermal conductivity of yak wool down and coarse hair

№	Fiber Color		Thermal conductivity, $x10^{-4}$(cal/cm·^{0}C)	Mean diameter, μm
1	Down/by color/	White	2.7±0.06	18.5±3.5
		Light blue, grey	2.20±0.05	18.3±3.7
		Brown	1.60±0.04	18.2±3.42
		Dark	1.80±0.03	18.3±3.5
		Average	2.08±0.04	**18.3**± 3.53
2	Coarse hair /by color/	White	3.50±0.09	45.7± 11.6
		Light blue, grey	2.80±0.06	43.0±11.9
		Brown	2.00±0.06	51.9±11.8
		Dark	2.20±0.06	55.5±11.8
		Average	2.63±0.07	**49.0**±11.8

Table 3 shows that down with an average diameter of 18.3 μm has an average thermal conductivity of $2.08x10^{-4}$ (cal/cm ^{0}C) and coarse hair with an average diameter of 49.0 μm has an average thermal conductivity of $2.63x10^{-4}$ (cal/cm ^{0}C). With a correlation of r = -0.80 for down and r = 0.86 for coarse hair, it is evident there is a strong correlation between thermal conductivity and fiber diameter.

Table 4

Water absorptivity of yak wool

Fiber	Color	Average wetting angle, degree	Wetting level	Force of interactive solid-liquid	Surface
Down	I	147.5±1.37	Very little wetness	Low wettability	non-absorptive
	II	145.4±1.52	Very little wetness	Low wettability	non-absorptive
	III	146.5±1.44	Very little wetness	Low wettability	non-absorptive
	IV	146.8±1.04	Very little wetness	Low wettability	non-absorptive
		146.5±1.34			non-absorptive
Coarse hair	I	146.1±1.37	Very little wetness	Low wettability	non-absorptive
	II	146.2±1.51	Very little wetness	Low wettability	non-absorptive
	III	148.5±1.45	Very little wetness	Low wettability	non-absorptive
	IV	147.6±1.45	Very little wetness	Low wettability	non-absorptive
		147.1±1.44			

$t_b = 1.5 < t_{st} = 2.776$ experiment shows to be realistic (p=0.05)

As shown in Table 4, the average wetting angle for each color of yak wool is approximately 146.50° for down and 147.10° for coarse hair. A comparative study on the relationship between the absorptivity of yak wool and its fiber diameter was conducted and the results are summarized in Table 5 below.

Table 5

Relationship between water absorptivity and fiber diameter

Sample Color		Wetting angle, degree	Diameter, μm
Down /by color/	White	147.5±1.37	18.5±3.5
	Light blue, grey	145.4±1.52	18.3±3.7
	Brown	146.5±1.44	18.2±3.42
	Dark	146.8±1.04	18.3±3.5
	Average	**146.5**±1.34	**18.3**± 3.53
Guard hair /by color/	White	146.1±1.37	45.7± 11.6
	Light blue, grey	146.2±1.51	43.0±11.9
	Brown	148.5±1.45	51.9±11.8
	Black	147.6±1.45	55.5±11.8
	Average	**147.1**±1.44	**49.0**±11.8

In Table 5, the wetting angle for down with an average diameter of 18.3 μm is 146.50º and the wetting angle for coarse hair with an average diameter of 49.0 μm is 147.10º. When examining the relationship between the wetting angle and fiber diameter of yak wool, we found a low correlation of r = 0.39 for down and r = 0.40 for coarse hair.

Discussion

According to the Japanese JIS standard, the human body feels comfortable when Qmax≤0.1w/cm^2. [14-16]. We found that the yak wool surface has a thermal sensitivity of 0.051 w/cm^2 and 0.061 w/cm2 for down and coarse hair, respectively. From this, we see that both down and coarse hair meet the standard requirements and have a lower thermal sensitivity than JIS standard. Therefore, we can conclude that both down and coarse hair contain fibers that are comfortable to the human body.

The relevant studies have shown that the thermal conductivity of yak wool is several times less compared to other textile fibers [15], meaning yak wool is better at retaining the heat emitted from the body.

The mean value of yak wool's wetting angle is between $90 \leq \theta \leq 170$ degrees, which falls into the category of very low wettability [17]. We found that the wetting angle for down and coarse hair are 146.50 degrees and 147.10 degrees, respectively, meaning yak wool surface fibers contain non-wettable properties.

Conclusion

The mean value of warm and cold sensitivity (Qmax) of the Mongolian yak wool surface is 0.051 w/cm^2 for down and 0.061 w/cm^2 for coarse hair. This index has a high level of confidence (p=0.05) for down and coarse hair.

1. Although there are differences in the outcomes between down and coarse hair, there is a high level of confidence in the values of thermal conductivity coefficients for the four different colors of yak wool.
2. There is a strong correlation between the thermal conductivity and fiber diameter of yak wool, showing a correlation of r = -0.80 for down and r = 0.86 for coarse hair. In other words, the thermal conductivity will increase as the fiber diameter increases and vice versa. From this, it can be concluded that thin fibers of yak wool have a lower thermal conductivity in comparison to thick fibers.
3. With a high level of confidence, the average wetting angles for down and coarse hair are consistent with one another and across the four different colors of yak wool.
4. There is a weak correlation between the wetting angle and fiber diameter of yak wool, showing a correlation of r = 0.39 for down and r = 0.40 for coarse hair. This means that yak wool's water absorptivity and wettability are less dependent on its fiber diameter.

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