Fiber characteristics of qiviut and guard hair from wild muskoxen (*Ovibos moschatus*)[1]

J. E. Rowell*[,2], C. J. Lupton†, M. A. Robertson*, F. A. Pfeiffer†, J. A. Nagy‡, and R. G. White*

*Large Animal Research Station, Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks 99775-7000; †Texas Agricultural Experiment Station, Texas A & M University, San Angelo 76901-9714; and ‡Department of Resources, Wildlife and Economic Development, Government of the Northwest Territories, Inuvik, NWT, Canada X0E 0T0

ABSTRACT: In response to increasing commercial interest and the high market value of qiviut (the downy underwool of the muskox), we have employed standards and measurements used in the wool and cashmere industries to describe qiviut fiber characteristics. Fleece samples (qiviut with guard hair) were shaved from the midshoulder of 299 wild muskox hides of known sex and age (1, 2, 3, and 4+ yr) during the Banks Island, Canada, muskox harvest in November 1997. Samples were analyzed for fiber diameter distribution of raw fiber and qiviut, scoured and qiviut yields, and lengths of guard hair and qiviut fiber. We found a sex × age interaction for average fiber diameter (**AFD**) in raw fiber ($P = 0.002$) and qiviut ($P < 0.001$) only. Adult males had significantly coarser AFD than females (21.5 μm, males vs 20.1 μm, females and 18.2 μm, males vs 17.5 μm, females) for raw fiber and qiviut, respectively. Qiviut AFD from yearlings was 1.7 μm finer than the AFD of adult qiviut. Fiber diameter distribution (**SD**) decreased with age in the raw sample ($P < 0.003$) and qiviut ($P < 0.001$) and qiviut SD was greater ($P < 0.001$) in males than in females. Qiviut theoretical yield (% mass of fibers ≤ 30 μm) increased ($P < 0.001$) with age, and females had higher theoretical yields than males ($P < 0.001$). Scoured yield did not vary between sexes in any age class and averaged 93.3%. Qiviut staple length did not differ with either age or sex. In summary, differences between the sexes were small up to the 3rd yr, and these differences were not likely to be of commercial importance. However, considering that AFD is a primary commercial criterion of value, AFD changes from 16.5 μm in yearlings to 18.2 μm in adults and from 17.5 μm in adult females to 18.2 μm in adult males would be expected to result in significant differences in commercial value.

Key Words: Fiber Quality, Wool, Wool Producing Animals

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Introduction

As arctic-adapted, "goat-like" ruminants, muskoxen survive the cold by producing an insulating undercoat of soft down called qiviut. Qiviut is shed in a tightly synchronized moult each spring and hence can be readily combed from captive individuals. Adults produce as much as 2.6 to 3.5 kg annually (White et al., 1989). The commercial potential of qiviut has been recognized since the 1700s but was not realized until the first successful muskox farm was established in Alaska during the 1960s (Wilkinson and Teal, 1984). More recently, commercial harvests of wild muskoxen on Banks Island and elsewhere in the NWT, Canada, have made available large quantities of dehaired qiviut, qiviut yarn, and finished products. This activity has stimulated renewed interest in the agricultural potential of muskoxen in Alaska.

Early accounts described qiviut as a silky, gray-brown fiber with an average fiber diameter (**AFD**) of 11.3 to 15.3 μm and a length of 3.8 to 7.5 cm (Von Bergen, 1931) or 13.0 to 17.3 μm AFD with a length of 4.2 to 7.9 cm (Wilkinson, 1975). Flood et al. (1989) described hair follicle density and the cycle of hair growth and shedding using monthly skin biopsies from five captive muskoxen. The pattern of primary and secondary follicles in muskox skin was unremarkable, with

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[2]Correspondence: P.O. Box 757000 (phone: 907-474-6009; fax: 907-474-6967; E-mail: fnjer@uaf.edu).

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the exception of their extraordinarily high secondary:primary follicle ratio (37:1; Flood et al., 1989). All these studies were based on very small sample sizes from animals of mixed age and sex and all were from captive muskoxen. As a result, none of the studies produced a comprehensive description of the natural fiber, nor have they adequately examined the effects of age, sex, or nutrition on fiber growth. As a precursor to developing an industry around this relatively rare textile, it is important to establish a baseline to define qiviut quality. This study was conducted to provide a representative description of the physical properties of qiviut collected from healthy, wild muskoxen of known sex and age.

Materials and Methods

Between November 3 and 21, 1997, a native subsistence harvest for meat, hides, and qiviut from the muskox population on Banks Island, NWT, Canada provided an opportunity to collect qiviut samples from hides of muskoxen in different age and sex classes. Postmortems conducted immediately after slaughter by federal veterinarians and area biologists indicated that this was a robust, healthy population (Nagy et al., 1996; J. Nagy, unpublished observations). A small sample of raw fiber (qiviut with guard hair) was shaved from the midshoulder region of 299 muskox hides removed from animals of known sex and age (1, 2, 3, and 4+ yr old). Qiviut was shaved using a Sunbeam Supershearer hand piece and a Sunbeam multispeed drive unit fitted with a Hineger Ovira 13-tooth comb with a standard 4-tooth cutter (2000 Sunbeam Corp., Boca Raton, FL). Grid-sampling the hides would have provided the most representative qiviut samples, but this was not practical. For consistency, all samples were collected from the left midshoulder area beginning approximately 15 cm below the junction of the mane's edge and the beginning of the saddle. The mane and saddle have distinctly different hair texture and color and they provided recognizable reference points on the hides. An area approximately 20 × 20 cm was shaved to within an estimated 2 mm of the skin. This provided between 20 and 35 g of raw fleece for analysis. Animals were aged on the basis of horn development and tooth wear at the time of slaughter. Samples were sent to the Wool and Mohair Research Laboratory at Texas A & M University for analyses. Qiviut, as defined here, refers only to those fibers having a diameter ≤ 30 μm. Numerically, this typically accounts for more than 90% of the fibers present in a raw sample. Mini-cored (2-mm-diameter tubes) subsamples were measured using an Optical Fibre Diameter Analyser (**OFDA**; BSC Electronics Pty. Ltd., Myaree, Australia). In brief, the OFDA consists of a microscope fitted with a motor-driven stage, charge-coupled device camera, a video monitor, and a computer installed with image acquisition and analysis hardware and software (Qi et al., 1994). The software uses a series of algorithms to recognize and distinguish individual fibers (in the range 5 to 300 μm) from fibers lying side by side or contaminating debris. Because the fibers are cut to 2-mm lengths and distributed onto a slide before measuring, flattened fibers would tend to be measured across the major axis. There is a small possibility that a twisted fiber could be measured at the minor axis or points in between. Details on the OFDA and software are described elsewhere (Baxter et al., 1992). The OFDA was used to determine AFD, fiber diameter distribution (SD), and coefficient of variation (CV) in raw fiber and qiviut alone. The theoretical yield of clean qiviut was calculated from the OFDA histogram and is defined as the percentage of mass of fibers ≤ 30 μm. Cleaning, conditioning, subsampling, and measuring the muskox fibers for fiber diameter distribution followed the standard method of the International Wool Textile Organization (IWTO, 1998). The OFDA was calibrated with Interwoollabs IH tops of known AFD values. The American Society for Testing and Materials (ASTM) test methods were used to measure scoured yield of the raw sample (ASTM, 1998a). For staple length, guard hair was manually separated from qiviut and staple length of both guard hairs (n = 10) and qiviut (n = 10) for each animal were measured (ASTM, 1998b).

Data were analyzed using Sigma Stat 2.0 (SPSS Science, SPSS Inc., Chicago, IL) in a one- or two-way ANOVA design with sex and age as main effects and the sex × age interaction. Tukey's test was used to separate differences in the means. Data are presented as least squares means.

Results and Discussion

The muskox population on Banks Island has been harvested on a semiregular basis since 1982. These harvests have grown in scale and organization and are presently carefully regulated by Inuvialuit, territorial, and federal agencies. The collection of qiviut samples was opportunistic and provides a unique baseline for a description of the fiber. Because the qiviut was sampled from a single shoulder site on the hides, it may not represent the finest fiber produced by the animal. In goats and sheep, fiber characteristics from different body regions vary (Ryder and Stephenson, 1968), and preliminary information on the follicle density distribution in the muskox suggests this may be true in this species as well (Flood et al., 1989).

Compared with raw wool and mohair, the percentage scoured yield of the raw sample was consistently high in all age and sex classes, ranging from a mean low of 92.7% in 3-yr-olds to 93.7% in adults (Table 1). This is much higher than mean scoured yield for most breeds of sheep and even surpasses the high scoured yield reported for cashmere goats (Lupton, 1993). Muskox fleeces were very low in grease (excreted from the sebaceous gland) and suint (water-soluble, dried sweat from the sweat gland), and contamination with vegetable matter, dirt, and so forth, was minimal.

Table 1. Sex and age differences in guard hair and qiviut characteristics from 299 fleece samples collected from wild muskoxen on Banks Island, NWT, Canada in 1997 (presented as least squares)[a]

Item	Sex				Age					
	Female	Male	SE[b]	*P*-value	1	2	3	4+	SE	*P*-value
Number of samples	161	138	—	—	74	40	41	144	—	—
Scoured yield, %	93.2	93.4	0.20	0.497	93.4	93.5	92.7	93.7	0.28	0.07
Qiviut yield (mass of fibers < 30 μm), %	52.9	49.3	0.63	< 0.001	47.2[c]	51.7[d]	53.4[d]	52.2[d]	0.96	< 0.001
Guard hair staple length										
Mean, cm	11.9	12.5	0.20	0.067	11.5[c]	10.9[c]	13.1[d]	13.4[d]	0.26	< 0.001
SD, cm	1.5	1.4	0.08	0.917	1.3[cd]	0.9[d]	2.0[e]	1.5[ce]	0.15	< 0.001
CV, %	11.1	10.7	0.60	0.622	10.6[c]	8.0[c]	14.3[d]	10.7[c]	0.82	< 0.001
Qiviut staple length										
Mean, cm	5.2	5.2	0.10	0.626	5.1	5.1	5.4	5.3	0.13	0.287
SD, cm	0.5	0.5	0.03	0.901	0.5	0.5	0.5	0.5	0.03	0.846
CV, %	9.6	9.4	0.69	0.779	10.2	9.7	8.8	9.3	0.67	0.515

[a]All samples were shaved from the left shoulder of muskox hides.
[b]Pooled standard error.
[c,d,e,f]Within rows, means without a common superscript differ ($P < 0.05$).

Staple length of the guard hair increased with age, whereas staple length of the qiviut was relatively constant among age groups and between the sexes (Table 1). The association of increasing guard hair length with age stems from the fact that guard hair is not shed annually but continues to grow over several years. Most authors estimate 3 to 4 yr for full guard hair coat development (Tener, 1965; Wilkinson, 1975; Flood et al., 1989). The relatively short guard hair length reported here is primarily a function of sampling site. The long, characteristic "skirt" hairs are not typically found high on the shoulder region. The consistency of qiviut staple length is related to the fact that these fibers are shed and replaced every year, achieving their full length each growing season. The insulation provided by qiviut is critical for winter survival and it is not surprising to see equivalent qiviut growth across age and sex classes. The mean staple length of approximately 5 cm reported here is lower than published staple lengths, which range as high as 8 cm (Wilkinson, 1975). This is probably a function both of sampling site and of the fact that the samples were shaved from hides as opposed to being shed. At the time of harvest in November, qiviut should have been near the end of its growth phase (Flood et al., 1989; Robertson, 2000) and hence close to maximum length. Among captive muskoxen in Fairbanks, qiviut growth rate slowed considerably in October, although continued growth was observed through November (Robertson, 2000).

The theoretical qiviut yield was significantly lower in yearlings than in the older age classes and it was greater in females than in males (Table 1). The reported qiviut yield is an estimate of the maximum percentage of qiviut that could be separated from the raw sample in a commercial dehairing process. The values reported here for muskoxen are more than double those reported in a study with cashmere goats (Lupton et al., 1995).

One of the most important criteria for determining the value and end-use of a fiber is AFD (Qi et al., 1994). In this study, AFD varied from 19.5 μm (2-yr-old females) to 21.5 μm (adult males) for raw fiber and 16.5 μm (yearling males) to 18.2 μm (adult males) for qiviut (Table 2). Fiber diameter of both raw fiber and qiviut predictably coarsened with age, these changes being most noticeable in qiviut (Table 2). A sex × age interaction occurred in both raw fiber AFD ($P = 0.002$) and qiviut AFD ($P < 0.001$). Although the sex differences were significant in the adult age class, real differences were small (1.4 μm in raw fiber and 0.7 μm in qiviut) and reflect the unexpectedly low SE. The coarsening of fiber with age and sex was not as dramatic as that seen in cashmere goats (Lupton, 1989), in which a 1.3-μm difference typically exists between the first and second fleece with a continued coarsening rate of about 0.5 μm per year. Nonetheless, considering the high value placed on fine fibers, a difference of 0.7 μm between adult males and females and 1.7 μm between yearling and adult males could prove commercially significant. Recently, a 1 to 2-μm difference in the AFD of mohair (a less valuable and coarser fiber than qiviut) resulted in price differences in excess of $4.40/kg raw material (Lupton and Pope, 2000).

The qiviut fiber diameters reported here are considerably coarser than the 11.3 to 15.3 μm (Von Bergen, 1931) or 13.0 to 16.9 μm (Wilkinson, 1975) previously reported for muskoxen. In this study we defined qiviut as all fibers between 0 and 30 μm. We chose this cut-off for three reasons. First, commercially dehaired qiviut typically contains only a very small percentage of fibers coarser than 30 μm (Figure 1). Second, most fiber diameter histograms of raw muskox fiber exhibit fine-fiber distributions that peak in the 15- to 17-μm range and taper off to almost no fibers in the 30- to 40-μm range (Figure 1). Third, this cut-off is used commercially to define another luxury down fiber, cashmere (ASTM, 1998c). In addition, research has shown that fiber ends exceeding 30 μm cause mechanical irritation of the skin, referred to as the "prickle factor" (Hansford, 1992).

Table 2. Sex differences (F = female, M = male) within age class for average fiber diameter (AFD) of raw fiber and qiviut from 299 fleece samples collected from wild muskoxen on Banks Island, NWT, Canada in 1997 (data presented as least squares means)[a]

Average fiber diameter	1 yr F (n = 32)	1 yr M (n = 42)	2 yr F (n = 22)	2 yr M (n = 18)	3 yr F (n = 25)	3 yr M (n = 16)	4+ yr F (n = 82)	4+ yr M (n = 62)	P-value for main effects: Sex	Age	Sex × age
Raw fiber											
Mean, μm	19.9	19.8	19.5	20.4	20.1	20.6	20.1[b]	21.5[c]	< 0.001	< 0.001	0.002
SD, μm	13.8	13.9	12.7	13.2	12.9	12.5	12.6	13.5	0.270	0.004	0.146
CV, %	69.3	70.1	65.1	64.7	64.0	60.2	62.2	62.8	0.385	< 0.001	0.213
Qiviut											
Mean, μm	16.7	16.5	16.9	17.3	17.5	17.8	17.5[b]	18.2[c]	< 0.001	< 0.001	< 0.001
SD, μm	4.9	5.0	4.8	4.9	4.6	4.8	4.6	4.7	< 0.001	< 0.001	0.206
CV, %	29.6	30.1	28.3	28.4	26.6	26.9	26.3[b]	25.8[c]	0.442	< 0.001	0.006

[a]All samples were shaved from the left shoulder of muskox hides.
[b,c]Within an age class and a row, means without common superscripts differ ($P < 0.05$).

Both Von Bergen (1931) and Wilkinson (1975) subjectively defined qiviut by manually separating what appeared to them to be qiviut and guard hair. Von Bergen's qiviut measurements came close to, but did not exceed, 30 μm, whereas in Wilkinson's study the upper limit ranged from 23 to 47 μm. Von Bergen worked with an extremely small sample size (n = 3) and measured individual fibers, many near the root end, which he acknowledged averaged 1 to 2 μm finer than the middle of the fiber. Wilkinson's study was also limited by small sample size (n = 14, for fiber diameter) and over half of the animals were ≤ 2 yr old. Both studies used qiviut from captive muskoxen of original Greenland stock. Although molecular genetics has identified few differences among geographically diverse muskox populations (Groves, 1997), visual and morphological differences are well established (Rowell, 1990). The influence of genetics on qiviut fiber diameter needs to be investigated. Both genetics and nutrition are known to influence fiber diameter in goats and sheep (Ryder and Stephenson, 1968). Recent work in captive muskoxen reported increased fiber diameter with methionine supplementation, clearly demonstrating the importance of nutrition in qiviut fiber growth, even under traditional captive feeding regimens (Robertson, 2000).

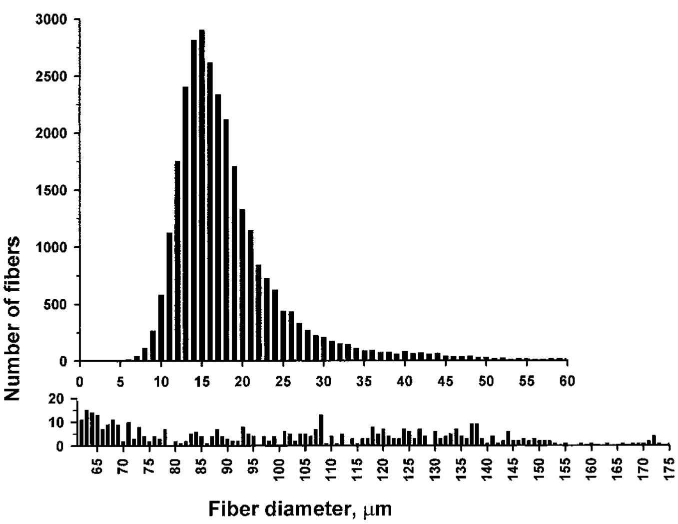

Figure 1. The fiber diameter distribution of a raw fiber sample shorn from the neck/shoulder region of a muskox. The sample was measured using an Optical Fibre Diameter Analyser (OFDA) and illustrates the distribution of qiviut (4 to 30 μm), intermediate fibers (31 to ~60 μm), and guard hair (> 60 μm). The lower panel continues the tail of the histogram. The scale on the y-axis in the lower panel has been enlarged for clarity. In this sample 29,500 fibers were counted, giving an average fiber diameter of 19.4 μm, SD of 12.9 μm, and a CV of 66.4%, with 8% of the fibers ≥ 30 μm.

Variability in fiber diameter, reported here as SD and CV of AFD for both raw fiber and qiviut, is generally considered of secondary importance in fiber processing (Lupton, 1995). However, variability in fiber diameter does affect processability and yarn uniformity (Hansford, 1992; Lupton, 1995). Females had a lower qiviut SD than males ($P < 0.001$, Table 2). This is not surprising, considering that females had a lower AFD than males and a strong, positive correlation exists between AFD and SD in all types of wool (Lupton, 1995). Because CV accounts for increasing AFD, it is considered more useful for describing fiber diameter variability. A sex × age interaction in CV ($P = 0.006$) paralleled that of qiviut AFD with sex differences ($P < 0.05$) in the adult age class. However, in this study, both qiviut SD and CV decreased with age ($P < 0.001$), whereas AFD increased (Table 2). The change in CV from almost 30% in yearlings to 26% in adults is substantial, and the negative relationship between AFD and both measures of variability is counter to measurements made on wool (Lupton, 1995) and other animal fibers. Additionally, the absolute magnitude of qiviut SD and CV are high relative to AFD. The U.S. Standards for Wool Grades set a maximum SD of 3.59 μm for an AFD of ≤ 17.70 μm (USDA, 1966). Lupton et al. (1995) reported a SD of

3.64 μm for 54 raw cashmere samples having an AFD of 17.65 μm. The qiviut SD and CV determined here from OFDA calculations are high compared with those of wool and cashmere.

Flood et al. (1989) identified a population of fibers of variable diameter, produced by primary follicles. These fibers were finer than "skirt" hairs but coarser than qiviut. The presence of fibers of variable diameter, shed together with qiviut, could account for the relatively large SD identified here and its negative relationship with AFD.

Previous descriptions of the muskox coat as bilayer (outer guard hairs protecting an inner layer of qiviut) ignore this third fiber type. This group of fibers is easily visible in combed fleeces and is referred to by spinners as the "medium" or "intermediate" hair (Cornwall, 1983). Intermediate hairs are fine like qiviut near the root end, coarsen considerably toward the tip, are shed annually with the qiviut, and can be medullated (Lupton and Rowell, unpublished observations). We believe this group accounts for most of the fibers between 30 and 50 μm (Figure 1) and is an important consideration in dehairing processes. Intermediate fibers seem to have been included with beard hair by Von Bergen (1931) and variously distributed between both qiviut samples and guard hair in Wilkinson's (1975) study. We have no information on the density or distribution of intermediate hairs over the body. Flood et al. (1989) took skin biopsies from three regions and, of these, primary follicles producing intermediate fibers were found in the neck and saddle regions but not the rump. The distribution of this fiber type and degree of medullation awaits future investigation. The fiber diameter distribution described here and illustrated in Figure 1 seems to be a unique characteristic of muskox fiber.

Implications

An objective description of fiber characteristics from healthy, free-ranging muskoxen provides information that is crucial to the establishment of quality guidelines. With this baseline, we can now begin comparing fiber characteristics among different wild populations and captive vs wild animals to further understand the role of genetics and the importance of nutrition in qiviut growth. Understanding differences in fiber characteristics from different regions on the animal will enable selective qiviut harvesting, and knowledge of the raw fiber characteristics provides a basis for evaluating commercial processing (dehairing) efficiency and quality.

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