**ABSTRACT**

**GREER, J. SUZANNE.** Evaluation of Non-Traditional Animal Fibers for Use in Textile Products. (Under the direction of DR. PAMELA BANKS-LEE.)

Textile products are composed of a range of materials and fibers. The natural protein fibers that are currently used in textile production such as wool, mohair, and silk can be very costly to the manufacturer and consumer. A non-traditional protein animal fiber, such as dog hair, can prove to be a cheaper, environmentally friendly, and very suitable substitute for the traditional protein fibers used today in textile processing. The use of this abundant protein fiber is very possibly a promising new avenue for the textile industry.

This thesis explores the feasibility of using non-traditional protein animal fibers, such as dog hair in conventional textile products. Experimental analysis is used to determine if the properties of these particular protein fibers make them suitable for use in textile applications. Physical properties of eighteen dog breeds were determined and compared to traditional animal hair fibers.

Results show it would be reasonable to consider dog fiber as a possibility for conversion into staple yarns. With strength, percent strain, and modulus, as a basis, dog fibers would perform equally as well as traditionally used animal fibers, and possibly better in certain instances. The following breeds should be considered as candidates for short staple processing: American Eskimo, Poodle, Sheep Dog, Shih Tzu, Schnauzer, Labrador Retriever, Pekingese, and Westie. The dog breeds that would be appropriate for long staple processing are as follows: Bichon Frise, Cocka-Poo, Lhasa Apso, Pomeranian, and Australian Shepherd.

# Evaluation of Non-Traditional Animal Fibers for Use in Textile Products

By

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## BIOGRAPHY

The author was born on April 18, 1978, in Wilmington, North Carolina. She spent her entire childhood in Whiteville, North Carolina. She received her elementary and secondary education in the Whiteville City Public School System. She entered Southeastern Community College in Whiteville, North Carolina, in August of 1996. She transferred to North Carolina State University in January 1998, and received a B.S. in Textile Technology and Design in May 2001. She continued on at North Carolina State University to complete the requirements for a M.S. in Textile Management and Technology.

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# 1. INTRODUCTION

Producers of textile goods are always in search of new and innovating fibers to use for consumer products. Because of the constantly changing needs of today's consumers, and the ever-changing environmental impact of production, ideal fibers that will meet consumer needs and at the same time be environmentally friendly are in demand. A fiber that meets both of these important criteria could quite possibly come from 'man's best friend', a dog.

One might ask themselves why this natural animal protein fiber has been overlooked for so long. The art of using dog hair in textile products has been practiced for centuries by individual artisans, but never used commercially. Textile producers have been commercially making products containing fibers such as wool, mohair, cashmere, and camelhair for hundreds of years, and they all come directly from an animal's back. So why not use the hair from the back of an animal that almost everyone has in his or her own home or backyard? The answer to that question might possibly be because the majority of the population does not understand the properties of dog hair, and how it could be put into the same category as commonly used protein fibers like wool and mohair.

The objectives of this research are 1) to determine the properties of dog hair, and 2) to pinpoint which dog hair, or *chiengora* fibers should be considered possible candidates for commercially producing yarns and/or fabrics.

In today's society, recycling, being kind to the environment, and making a dollar stretch are some of the many things that drive civilization and the economy. Therefore, discovering a usable fiber, such as dog hair, that could possibly be blended with other protein fibers to make a more economical yarn or fabric, that is inexpensively recycled, biodegradable, and hence environmentally friendly, would be a huge step in the future of the textile industry.

This research study is possibly one of the first of its kind to provide evidence of quantitative values to dog hair properties. From these properties, one can go further to establish what types of products can be created using dog hair fibers. Could dog hair be used in products such as carpet backing, nonwoven vehicle head and trunk liners, throw blankets, or even knitted and woven apparel items? This research should hopefully be a firm beginning to answer questions such as these about this humane and quite interesting form of recycling a current waste product.

# 2. LITERATURE REVIEW

## 2.1 INTRODUCTION

Animal hairs and secretions have a long history as raw materials for textile products. Hair fibers from animals such as camels, sheep, and goats have been used in the production of staple yarns for many centuries. These yarns were used to produce fabrics for apparel and home furnishing applications. There are several properties that determine the suitability of a particular fiber for use in textile applications. These properties include fiber aspect ratio, tenacity, elongation, modulus, length, and linear density.

## 2.2 FIBER PROPERTIES

It is important to have some background information about some of the important properties on which this research study focused. These properties included fiber denier, tensile strength/tenacity, % elongation/strain, and modulus. A description of each of these properties follows.

### 2.2.1 Fiber Linear Density

Fiber linear density is a measurement of fiber size expressed as mass per unit length. For fibers, it is typical to give the linear density in units of denier (grams per 9000 meters) or micronaire (micrograms per inch). When thinking about linear density and how it relates to the size of a fiber, the larger the linear density, the larger the fiber diameter.

### 2.2.2 Tensile Strength/Tenacity

Tensile strength or tenacity of a fiber indicates the amount of force a fiber will support before breaking [1]. As a general rule, the higher the linear density of a fiber, the higher the fiber tensile strength. Tensile strength is normally reported in grams force, while tenacity is normalized with respect to the fiber size and reported in grams force per denier. This property, though a useful measure is often given too much emphasis. Kaswell [1] states that using tenacity as a general measure of value is not valid. The validity of the measurement is determined by end use circumstances. For example, if a certain application calls for a strong fiber, then tenacity is considered an important criterion. However, in instances where weaker fibers are required or acceptable, tenacity becomes less important. Therefore, tenacity should be considered as only one of a number of properties to be included in the evaluation of fibers or yarns [1].

In the case of animal fibers, fiber strength increases almost linearly with the fiber cross-sectional area, more particularly the cross-sectional area of the thinnest place along the fiber [2]. Therefore, the fiber strength divided by the fiber cross-sectional area is almost constant for a particular type of fiber [2]. ASTM D 3822-01, *Standard Test Method for Tensile Properties of Single Textile Fibers*, states that as the length of the test specimen decreases, the tensile strength is likely to increase, but the accuracy of the tensile properties determined may decrease, which may require the need to increase the number of test specimens. This is particularly true for those properties dependent on the measurement of elongation, since the shorter lengths increase the relative effect of slippage and stretching of the test specimens within the jaws of either clamp [2].

### 2.2.3 Elongation/Percent Strain

Elongation is defined as a measure of the extent to which a fiber or yarn stretches before it ruptures or breaks. The elongation value is directly related to the gage length, or the sample length between the grips on a tensile testing machine. This means that the percent elongation value will change if the gage length is altered [2].

This property demonstrates how extensible a fiber or yarn can be when stressed. At times it is favorable for a fiber to be extensible, where other times an inextensible fiber may be more suitable [1]. For example, in applications such as towropes and seat belts, one needs a fiber with high extension, whereas in an instance where it is necessary for easy breakage, one would need a fiber with low extension. The higher the tenacity and extension of a fiber, the higher is its capacity to absorb energy. This energy absorption is important in evaluating materials for abrasion resistance, resilience, and crease resistance [1].

Elongation is also directly related to fiber fineness. As a general rule, the finer the fiber, the lower the elongation and breaking load. For example, camel hair has a similar elongation at break as wool, but camel hair is much stronger which indicates that camel hair is not as fine as wool [1].

**2.2.4 Fiber Modulus**

Fiber modulus relates two parameters, the ratio of stress (load) to strain (elongation) at loads below the elastic limit. Textile fibers are not completely elastic, which means that their strain is not proportional to their stress. Instead, textile fibers are considered to be visco-elastic. For visco-elastic materials, the force required to deform the fiber is related to both the amount and rate of deformation. Therefore, since modulus is not constant, it must be defined and listed for each particular situation. Modulus is best represented as a load-elongation diagram [1].

The parameters of fiber size, tenacity, modulus, and percent strain are important when deciding the appropriate fiber for a product. These fiber properties will greatly influence yarn and fabric properties and thus play a large part in determining product suitability for a particular end use.

## 2.3 TRADITIONAL ANIMAL FIBERS

Society has used animal fibers for clothing, shelter, rugs, and many other miscellaneous items for decades. Animals have been part of everyday survival since long ago when they were hunted for food, and then the skin and hair served many other purposes. The most well known and most used of these exotic fibers today are wool, mohair, cashmere, and camelhair. Each fiber has its own distinguishing characteristics, and serves unique purposes.

### 2.3.1 Wool

Wool, the hair of a sheep, has been used for clothing, upholstery, and carpeting for many years. It possesses many fine qualities such as warmth and water resistance, but also has its downsides, such as being a very dirty fiber initially and having problems with shrinkage.

#### 2.3.1.1 Properties

Innumerable minute projections and indentations, known as serrations, appear along the whole surface of the shaft of the fiber as shown in Figure 1 [3].

**Figure 1** [3]
Wool fibers with outer scale coverings

Because of this, when wool fibers come together, the serrations grip one another and assist in the production of a strong yarn. These serrations also serve to protect the fiber during manufacturing processes [4]. These scales face towards the tip of the fibers, and cause a directional effect, which is important in the frictional behavior of wool [5]. One of the outstanding qualities of wool is its elasticity and resilience [4]. It has the ability to return to its natural length after being stretched. The elasticity of wool is very important when determining the comfort of close-fitting garments. Elasticity is also important in the performance of carpets causing them to recover when crushed [4]. A wool fiber can be stretched 25 to 30% its natural length depending on the wool quality [6]. Because of this elasticity, wool is often said to have two lengths, the apparent length and the true length. The apparent length represents the length of the fiber before stretching to the extended length. The true length is only revealed when the fiber is measured when stretched under just enough tension to pull out the crimp. Wool appears to have somewhat of a three dimensional crimp, which means that it 'rolls' as it crimps, similar to a ribbon as shown in Figure 2 [3]. The average length of a wool fiber is 1 to 8 inches [7]. Because of wool's great resilience and good elastic recovery, it has superb wrinkle recovery [3]. An average diameter for wool is 8 to 70 microns (0.0018 to 0.003 inches) according to Schwarz [7].

The cross-section of wool has an oval to circular shape and consists of three different parts, as shown in Figure 3 [3]. The outer part of a wool cross-section is called the cuticle, the middle layer is called the cortex, and the inner part, or core, is the medulla.

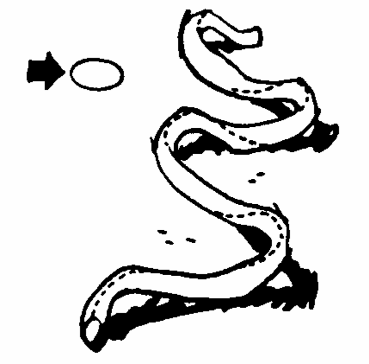

**Figure 2** [3]
3-Dimensional wool crimp

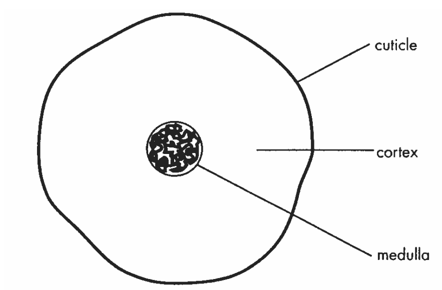


**Figure 3** [3]
Cross-section of wool

Table 1 [8] is a summary of some of the significant properties of wool fibers such as the scale patterning, cross-sectional, and whole mount views. Scale patterning is a close look at how the scales arrange themselves along the length of the fiber. This patterning is seen by making a scale cast. A scale cast can be made by using a few drops of a 20% solution of polyvinyl acetate in benzene to drive off the benzene leaving a thin layer of plastic. The fibers are placed on the plastic layer and covered with a clean slide. The slides are then heated under a pressure of about 10 pounds until a test piece shows that the plastic has softened. After cooling, the slides are separated and the fibers are removed, leaving casts in the plastic. This scale cast shows if the scale pattern changes along the length of any of the fibers [8]. Cross-sectional and whole mount views are microscopic views of a cut fiber and the complete length of the fiber. The table has this information for different sizes of the fiber, which are fine, medium, coarse, and kemp fibers. Descriptions of the scales, whole mounts and cross-sectional views are given for each fiber size.

For the whole mount as seen in Table 1 [8], wool has an irregular diameter no matter what the fiber size. There is either no medulla or it is considered very fragmental for most wool fibers. Wool's pigment distribution is mostly none to dense. The cross-section of wool is usually circular to oval. An irregular mosaic, yet smooth scale pattern is observed on most wool fibers.

The coloring of wool fibers is mainly light cream, but can be found in brown or black. Wool's density ranges from 1.33 to 1.35 grams/cc [7]. Also, wool has some luster, but the finer the scales, the duller the fiber. During processing, when fine fibers are spun into combed yarns with fibers laid nearly parallel, a subtle luster is evident [3]. An example of this type of luster is seen in fine suiting materials [3].

Despite the fact that wool has a low tensile strength ranging from 1.28 to 1.59 grams per denier, it can be made into very durable fabrics with good abrasion resistance, which can be restored to good looks over a long wear life. Also, pilling is not a very big problem with wool fabrics because the pills can be easily removed with a stiff bristle brush [3].

Wool's ability to absorb moisture is another one of its attributes. It is considered the most hygroscopic of all of the protein fibers used in textiles today. Wool can hold as much or more than 30% of its own weight in moisture without feeling wet, and gives up moisture slowly [7]. In Figure 4 [3], the spindle-shaped cortical cells found in the section under the cuticle of wool called the cortex are what make wool so absorbent because these cells take up and hold moisture [3]. The percent moisture affects wool's breaking strength, elasticity, and weight. An increase in moisture will decrease the breaking strength of wool, but increases its elasticity [7].

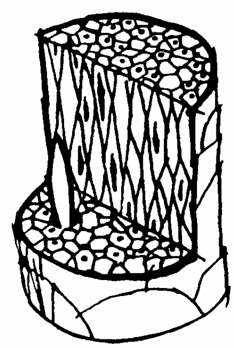

**Figure 4** [3]
Wool fiber structure
Cuticle, scales, and cortical cells

**Table 1** [8]
Properties of Wool Fibers

| ANIMAL | WHOLE MOUNT | | | CROSS-SECTION | | | | SCALE PATTERN | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Profile** | **Medulla** | **Pigment Distribution** | **Contour** | **Medulla** | **Cuticle** | **Pigment Distribution** | **Base** | **Mid-Length** | **Tip** |
| SHEEP | ***Fine*** | | | | | | | | | |
| | Irregular diameter<br>Scale margins prominent | None | Mostly none<br>Some sparse to dense | Circular to oval | None | Thin | Mostly none<br>Some sparse and even<br>Some dense | Irregular waved mosaic<br>Smooth<br>Near margins | | |
| | ***Medium*** | | | | | | | | | |
| | Irregular diameter<br>Scale margins prominent | Some none<br>Some fragmental | Mostly none | Circular to oval | Some none<br>Some circular to oval | Thin | Mostly none<br>Some sparse and even<br>Some dense | Irregular mosaic, usually waved<br>Smooth<br>Near margins | | |
| | ***Coarse*** | | | | | | | | | |
| | Irregular diameter<br>Scale margins prominent | Varies from none to interrupted<br>Continuous wide lattice | Mostly none<br>Some sparse to dense | Circular to irregular | Some circular to oval<br>Some wide to concentric | Thin | Mostly none<br>Some sparse and even<br>Some dense | Irregular mosaic, usually waved--or regular mosaic and some changing to irregular mosaic<br>Smooth<br>Near margins | | |
| | ***Kemps*** | | | | | | | | | |
| | Irregular diameter<br>Scale margins prominent | Continuous<br>Wide lattice | Mostly none<br>Some sparse to dense | Irregular<br>Some ribbon type | Wide concentric | Thin | Mostly none<br>Some sparse and even<br>Some dense | Regular mosaic | Irregular mosaic<br>Smooth<br>Near margins | |

Wool does not readily conduct heat; therefore, wool garments act as an insulator and help to keep the body at an even temperature during excessive hot or cold weather. When manufactured into garments, wool fibers create millions of tiny pockets that trap the air and keep it almost still, thus keeping the body at an even temperature [4]. Also, wool does not readily burn when exposed to an open flame. The burn that it has is like a bead-like ash that is cold which basically extinguishes the flame. This non-flammable characteristic makes wool a very safe textile fiber.

Wool also has an incredible ability to felt and entangle to form compact fabrics or tissue. A high degree of felting enables the production of a very dense, compact material after fabric shrinkage. Felting is mainly a physical action because it results from the small projections or serrations of neighboring fibers interlocking with each other until the component fibers become united to form a close, compact tissue of fabric. Fiber fineness, crimp, and elasticity are other factors that contribute to high felting capacities [4].

Wool is one of the most durable textile fibers [4]. Its irregular and non-solid structure allows it to be twisted and bent out of its usual form without being broken, giving wool its long-lasting qualities. The coarseness of the wool fiber is what makes wool garments resistant to wear and tear. Drape is another outstanding property of wool [4]. This aspect is very important when considering outerwear garments, upholstery fabric, and drapes [4].

#### 2.3.1.2 Processing

The most important characteristic of wool from a manufacturer's view is the length. The length of the wool fiber determines the method of preparation for spinning the fiber into yarn. Generally, the longer the wool fiber, the higher the wool value because of the ease of manufacturing [4]. Because of the dirty nature of wool, a rigorous scouring process must be done before any other processing stage. Wool is scoured in warm water with soap and a mild soda ash solution. Scouring baths are equipped with automatic rakes to stir the fibers, and rollers between the vats. Wool can also be put through a carbonizing bath of dilute sulfuric acid or hydrochloric acid to burn out the foreign matter.

After the scouring process, the wool fibers go through a drying process to remove excess water [4]. Wool can still contain up to 40% moisture after completing the scouring process. The wool must be dried for storage purposes. If it is not dried properly, it may be attacked by mildew. However, if the wool is over dried, the fibers are damaged and may become discolored and electrically charged. The charge could make the fibers fly away from each other and cling to machinery in the manufacturing facility. The two most commonly used mechanical driers are the tier dryer and the drum drier. For effective operation, a constant temperature must be maintained in either type of drier, and the moist air from the drier must be exhausted into the outside atmosphere [4].

Crimp is thought to be an important factor in the manufacturing process, as well. During combing, the crimp is combed out, but during the finishing process, the fibers tend to return to their natural shape, thus tightening up and strengthening the material [4]. The serrations that wool exhibits also assist in the production of a strong woolen yarn. During processing, wool fibers are stretched to their true length and the subsequent return to their original length causes the yarn and the finished material to bind strongly together, thus adding to the strength and wearing capabilities of the fabric [4].

#### 2.3.1.3 End Uses

Wool is preferred to other materials for children's clothing; especially sleep wear, and elderly clothing because of its non-flammable nature [4]. Sometimes the coarse guardhair from wool, called kemp, is used as effect fibers in fabric such as tweed because it has poor dye uptake [3].

Wool is a very popular fiber used in winter clothing, such as sweaters, because of its great warmth. The thicker, harsher wool fibers are usually restricted to use in outer garments, where the finer and softer fibers can be used in top weight garments, such as sweaters [4]. Many men's suiting fabrics are wool, or contain a percentage of wool. Winter coats, socks, and scarves are often made from wool fibers. Because of wool's durability and natural resilience, it is also used in carpeting, rugs, and upholstery [4]. Wool possesses many qualities, which make it a versatile fiber.

### 2.3.2 Mohair

Mohair, the lustrous fleece of an Angora goat, has been regarded as one of the most luxurious and best quality fibers available to man [4]. Mohair is the number one produced fiber out of all of the specialty animal fibers today, but represents less than 0.05% of the total world fiber production [4]. Mohair's tremendous versatility is one of its main advantages [9]. It can be used for clothing and furnishing, and within these sectors, its end uses are endless [9]. The average price of mohair can fluctuate anywhere from $13/kg in 1979 to $8/kg in 2000 [10]. Mohair's affinity for dyes and its ability to absorb them completely makes the dyeing process easy during manufacturing [9].

#### 2.3.2.1 Properties

Generally, mohair is a straight, smooth, and naturally lustrous fiber [4]. Mohair exhibits the capability to be dyed deep, brilliant, and fast colors, where in contrast, it can also produce very distinctive muted tones. Naturally, mohair is white, however, occasionally, there are varieties of brown, black, and pink/red assortments. Good quality mohair is virtually free of medullation and kemp, which makes it a relatively clean fiber [4].

Mohair has low flammability, felting, pilling, and good durability. Because of its strength of about 13 grams/denier, it is classified as the strongest hair fiber [4]. Other physical properties of mohair are given in Table 2 [2]. Further attributes of mohair are its elasticity, luster, resistance to soiling, setting ability, abrasion resistance, drapeability, shapeability, moisture and perspiration absorption and release, insulation, and comfort. Mohair is almost non-crushable, therefore having great resilience. In addition, mohair fibers shed soil well by brushing clean easily [4].

**Table 2** [2]
Physical Properties of Mohair

| Property | Units | Mohair |
|---|---|---|
| **Tenacity** | g/den | 1.82 |
| **Breaking Extension** | % | 30 |
| **Elastic Modulus** | g/den | 40.8 |
| **Elongation at Break** | % | 40.4 |
| **Elastic Recovery:** | | |
| *Half Breaking Load* | % | 0.78 |
| *Half Breaking Extension* | % | 0.59 |
| **Work Recovery:** | | |
| *after 2% extension* | % | 96 |
| *after 5% extension* | % | 47 |
| *after 10% extension* | % | 28 |
| **Length Recovery:** | | |
| *after 2% extension* | % | 95 |
| *after 5% extension* | % | 75 |
| *after 10% extension* | % | 54 |

Mohair's scale structure gives it the attributes of smoothness, low friction, low soiling, good soil shedding, and low felting. As shown in Figure 5 [8], the scales are usually thin, flat, and relatively long [4]. These relatively large, plate-like scales also give mohair its luster [3]. Mohair's epidermal, or cuticle scales are faintly visible and hardly overlap [4]. They are anchored much more closely to the body of the fiber, giving the fiber a very lustrous smooth appearance [4].

Table 3 [8] points out physical properties of mohair fibers such as its mosaic and smooth scale patterning. Mohair has somewhat of a circular to oval cross-sectional shape and a regular diameter. Its pigment distribution ranges from none to occasionally very sparse. The scale patterning of mohair is fairly consistent from the root region of the fiber to the tip, which has a smooth, irregular mosaic pattern.

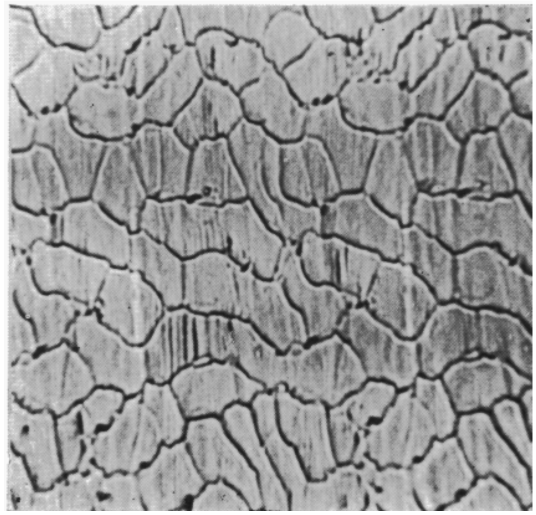

**Figure 5** [8]
Mohair scale pattern
Magnification 400x

The average length of mohair fibers is from 9 to 14 centimeters. Its diameter ranges from below 24 μm to 40 μm. Mohair fibers tend to be more even in diameter along their lengths than wool [4]. Generally, mohair is practically circular, having a ratio between the major and minor diameters of 1.12 or lower. Wool, on the other hand, has a ratio that is 1.2 making it more oval than mohair. Lower grades of mohair fibers are stated to be generally less circular than the better grades. Under the microscope, many animal fibers show black dots or little circles, which are caused by air filled pockets or vacuoles as shown in Figure 6,7, and 8 [8].

**Table 3** [8]
Properties of Mohair Fibers

| ANIMAL | WHOLE MOUNT | | | CROSS-SECTION | | | | SCALE PATTERN | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Profile** | **Medulla** | **Pigment Distribution** | **Contour** | **Medulla** | **Cuticle** | **Pigment Distribution** | **Base** | **Mid-Length** | **Tip** |
| **ANGORA GOAT** | ***Fine*** | | | | | | | | | |
| | Regular diameter<br>Scales very shallow<br>Frequently short streaks or vacuoles in the cortex | None | None<br>Occasionally very sparse | Circular to oval | None | Thin | None<br>Occasionally very sparse | Irregular waved mosaic<br>Smooth<br>Near to distant margins | | |
| | ***Medium*** | | | | | | | | | |
| | Regular diameter<br>Scales very shallow<br>Frequently short streaks or vacuoles in the cortex | Fragmental | None<br>Occasionally very sparse | Circular to oval | Circular to oval | Thin | None<br>Occasionally very sparse | Irregular mosaic mostly smooth<br>Sometimes slightly rippled or crenate<br>Near margins | | Waved<br>Crenate<br>Near margins |
| | ***Coarse*** | | | | | | | | | |
| | Regular diameter<br>Scales very shallow<br>Frequently short streaks or vacuoles in the cortex | Fragmental<br>Continuous | None<br>Occasionally very sparse | Circular to oval | Circular to oval | Thin | None<br>Occasionally very sparse | Irregular mosaic, smooth--or simple waved, slightly crenate<br>Distant to near margins<br>These patterns may occur at random along the length of one fiber | | |
| | ***Kemps*** | | | | | | | | | |
| | Fairly regular diameter<br>Scales not very prominent | Continuous<br>Wide lattice | Usually none<br>Occasionally sparse | Irregular<br>Some ribbon type | Wide concentric | Thin | Usually none<br>Occasionally sparse and even | Waved, crenate--or irregular, slightly waved mosaic, smooth<br>Near margins<br>Some transitional between the two patterns | | |

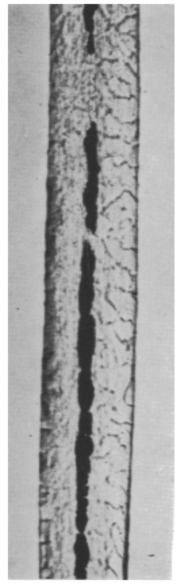

**Figure 6** [8]
Longitudinal view of mohair
(Black medulla caused by vacuoles)
Magnification 200x

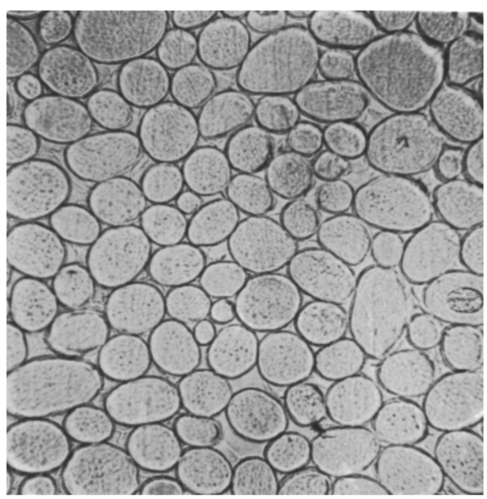

**Figure 7** [8]
Microscopic view of mohair cross-sections
(Black dots caused by vacuoles)
Magnification 200x

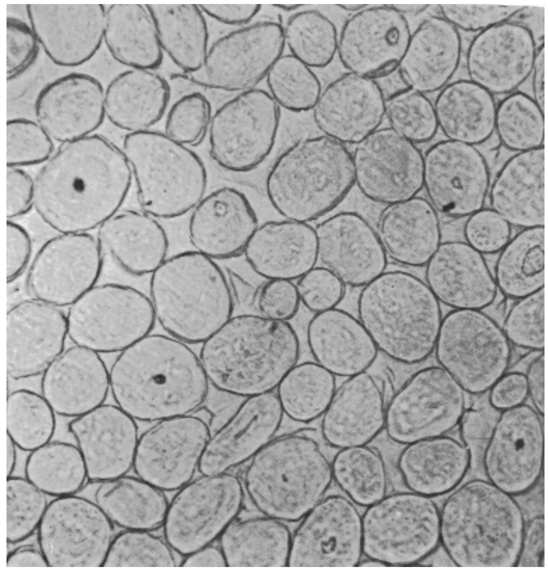

**Figure 8** [8]
Microscopic view of wool cross-sections
(Black dots caused by vacuoles)
Magnification 200x

**2.3.2.2 Processing**

Mohair is not an easy fiber to process, especially in drawing and spinning. Many companies are secretive about the processing of mohair because it provides them with a competitive edge. Because of mohair's low cohesion, it often necessitates that the fibers be supported during processing. Its generation of static electricity also poses a large problem in processing. Blending mohair with other fibers, such as wool, greatly reduces these processing concerns, as well as using lubricants and additives, and the appropriate processing machinery and conditions [2].

Fabrics made of mohair are very light in weight and have excellent insulation. Mohair fabrics are warm in the winter; yet comfortably cool in the summer. Mohair blends beautifully with other fibers, which of course reduces the cost of a fabric made partly of mohair [4].

**2.3.2.3 End Uses**

Mohair is used in apparel as well as non-apparel items. It has proven to be relatively unsurpassable in many non-apparel applications such as furnishings, blankets, and upholstery. It is particularly suitable for household textiles such as velour upholstery fabrics, curtains, and carpets [2]. Because of mohair's ability to shed dirt easily, it is used for paint roller covers because it releases the paint easily as well. The fiber is often used in boucle loop yarn to give fabric a light, airy, and warm feeling. Mohair's wiry property makes it suitable for use in braids and tailor's canvas [3]. It is often blended with wool for top quality blankets where the mohair content makes the fabric warmer, and at the same time lighter [9].

### 2.3.3 Cashmere

Cashmere is the under down of the domestic goat of central Asia and goats which are now raised in North America [11]. Cashmere is a very soft and luxurious fiber, which comes from the coat of a cashmere goat. It adds warmth, luster, and visual charm to garments and carpeting [9]. There is a long history of cashmere hair, the thick outer protective coat of the animal, being used for cloth and carpets in Asia [11]. Cashmere fibers were also used for weaving cloth for making tents for the nomadic herdsmen, who traveled with their goats seeking new pastures. With natural fibers increasing in popularity in the fashion world, new interest in cashmere fiber is occurring in many areas of the world. This unique, exotic fiber is finally getting the recognition it deserves [11].

#### 2.3.3.1 Properties

There are three key factors that explain why cashmere is regarded so highly. These factors are its extreme fineness and softness that give cashmere its tactile and visual appeal; its scarcity in relation to other fibers; and its image or charm [9]. Because of this prestige, cashmere has a very high price in the textile world [9]. The price of cashmere ranges any where from about $40/kg to $110/kg [9], as compared to wool ranging in costs from about $8/kg to $25/kg [12]. As compared with wool and mohair, cashmere is a much finer fiber [9]. The finer the diameter of cashmere, the higher the price for the down [11]. Cashmere also possesses a lot of crimp [11].

Cashmere fibers have an oval to circular cross-sectional shape, as shown in Figure 10 [8]. These fibers have a fairly thin cuticle. The scale patterning of cashmere that is shown in Figure 9 [8] is a regular waved mosaic pattern with slight ripples [8].

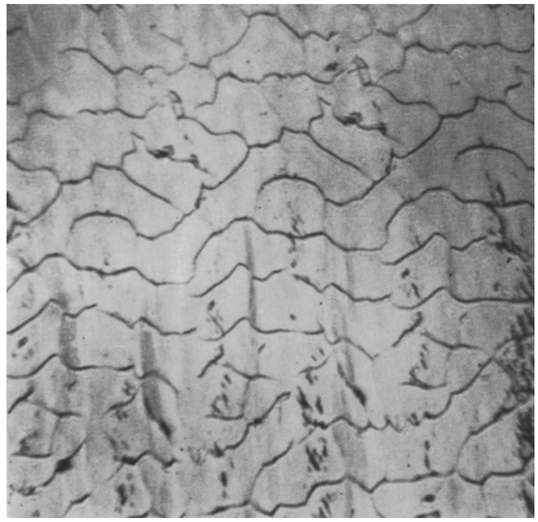

**Figure 9** [8]
Scale patterning of cashmere fiber
Magnification 400x

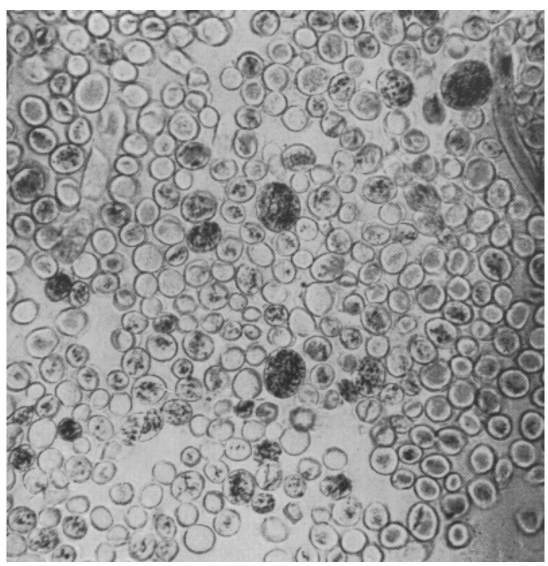

**Figure 10** [8]
Cross-sectional view of cashmere fibers
Magnification 200x

The longitudinal views of cashmere shown in Figures 11 and 12 [8], show that the tip region of the fiber has a different scale pattern than the root region of the fiber [8].

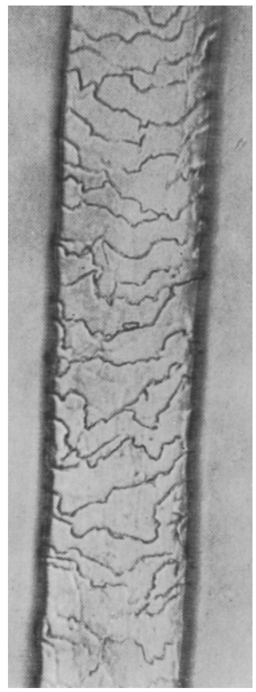

**Figure 11** [8]
Longitudinal view of cashmere scales (1)
(Tip region of the fiber)
Magnification 400x

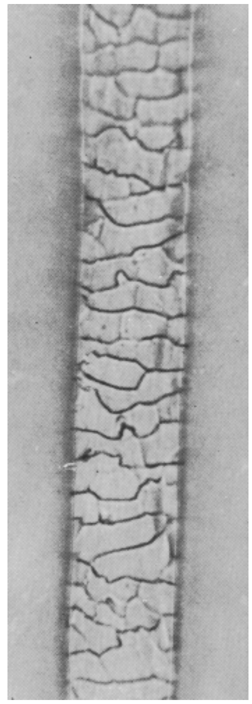

**Figure 12** [8]
Longitudinal view of cashmere scales (2)
(Root region of the fiber)
Magnification 400x

Cashmere also has a fairly regular diameter throughout the length of the fiber [8]. The diameter of cashmere ranges from 12.5 to 16.0 microns, where a standard diameter is considered to be about 15.5 microns. When considering length, the longer the cashmere fiber the better the quality. The Chinese Commodity Inspection Bureau (CCIB) specifies that a cashmere fiber should be longer than 32 mm, and a fiber length of 46 mm is considered long. White cashmere fiber is the preferred color because it is easiest to dye and produces the purest colors. Grey and brown are colors seen in cashmere fibers also [9].

Table 4 [8] highlights other properties of cashmere fiber such as its fairly prominent scales and usually concentric cross-sectional shape. Cashmere's medulla ranges from being not present, to being interrupted, to being continuous. The pigment distribution ranges from sparse to dense and even. The scale patterning of cashmere is basically a regular waved mosaic pattern [8].

**2.3.3.2 Processing**

The processing of cashmere is no easy task. Historically, the fibers were sorted by hand in factories called sorting sheds into grades and colors by women with trained eyes. Today, sophisticated laboratory equipment performs this sorting process, while also testing fiber properties. After sorting, the fibers go through a process known as willowing. This process removes any dirt and grit by feeding the fiber through a revolving machine that shakes out the grit and dust. Next, the fibers are scoured and then dehaired.

Dehairing separates the coarse guard hair from the precious inner down. Dehairing is a mechanical process involving several stages that must be performed in a controlled temperature of 80 to 85 degrees Celsius. This technique is kept secret because of the quality of cashmere that it produces. Only the under hair or 'down' is used for apparel applications. The hair that is removed, or the waste, has other end uses.

Before the dyeing process, the cashmere fiber should be scoured. This scouring process is very similar to the scouring process of wool. The fiber is cleaned using a mild detergent, dried, and is then ready for dyeing [11]. The dyeing of cashmere fibers is carried out in its 'loose' state [9]. When dyeing the actual fibers, the cleaned fibers can be lowered directly into the dye bath without the fiber being handled [11].

**Table 4** [8]
Properties of Cashmere Fibers

| ANIMAL | WHOLE MOUNT | | | CROSS-SECTION | | | | SCALE PATTERN | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Profile** | **Medulla** | **Pigment Distribution** | **Contour** | **Medulla** | **Cuticle** | **Pigment Distribution** | **Base** | **Mid-Length** | **Tip** |
| **CASHMERE GOAT** | ***Fine*** | | | | | | | | | |
| | Fairly regular diameter<br>Scale margins prominent | None | Some sparsely pigmented | Almost circular | None | Thin | Fairly even | Regular waved mosaic, smooth; distant margins | | |
| | ***Coarse*** | | | | | | | | | |
| | Regular diameter<br>Fairly prominent scale margins | Interrupted or continuous | Some fibres dense and even | Oval to circular, some flattened | Concentric | Thin | Dense in some fibres | Irregular waved mosaic<br>Slightly crenate-rippled; near margins | Waved, crenate<br>Near margins | |

After dyeing, the fibers are teased into roughly the same direction and oil is added to give resilience for the spinning process [9]. When dyeing a cashmere yarn or finished garment, the dyeing process is a bit easier and safer because there is less chance of felting [11].

Higher quality cashmere fibers are usually spun into knitting yarns, and the lesser quality fibers go into weaving yarns. The weaving sector of the textile industry is a much smaller customer for cashmere than the knitting sector. Blending cashmere with a small amount of silk strengthens the yarn without downgrading the cashmere fiber quality [9]. The higher the percentage of cashmere when blending with another fiber, the easier the spinning process becomes [11]. Production of cashmere was estimated at 5,000 tons per year in 1988 [9].

**2.3.3.3 End Uses**

The coarser cashmere fibers, 16.0 to 17.5 microns, are used primarily in knitwear and weaving, with fibers ranging from 17 to 21 microns chiefly used for weaving [9]. Overcoats are usually made of the coarser cashmere hairs. The fine cashmere hairs are used in sweaters [3]. The hair that is removed during the dehairing stage, which is discussed earlier in Section 2.3.3.1, is used in carpets, under felts, and interlinings for men's suits and jackets [9].

**2.3.4 Camelhair**

Camelhair holds a very prestigious quality image in the United States, and comes high in the league of luxury fibers for woven cloth. Just as the name indicates, this fiber comes from the coat of a camel, and is usually in shades of brown and grey [9]. The price of camelhair can range from $9/kg to $24/kg in the United States [5].

#### 2.3.4.1 Properties

The most common color of camelhair is a reddish brown with variants from brown to grey. The white fleece is the most valued, but is very rare [9]. Camelhair and cashmere share many of the same properties except for the fact that camelhair is a bit coarser [9].

Camelhair has two basic qualities, the coarse outer hair and the inner down fiber. The fine down fibers range in diameter from 19 to 24 microns and have a length of about 2.5 to 12.5 cm. The coarse fibers have a diameter of 20 to 120 microns and a length of up to 37.5 cm [9]. The cross-section of camelhair has an oval to circular shape as shown in Figure 13 and stated in Table 5 [7]. Figure 14 [8] shows that the scales of camelhair have an irregular mosaic pattern, yet they are smooth.

Table 5 [8] states that camelhair has a regular diameter and a smooth surface. The cuticle of the fiber is somewhat less dense compared to the rest of the length of the fiber. The pigment distribution is sparse near the medulla in the finer fibers, yet dense near the medulla in the coarser fibers.

Other characteristics of camelhair are its strength of 1.79 grams/denier, luster, smoothness, water repellency, warmth, fineness (9.55 denier), and camelhair is lightweight also [3].

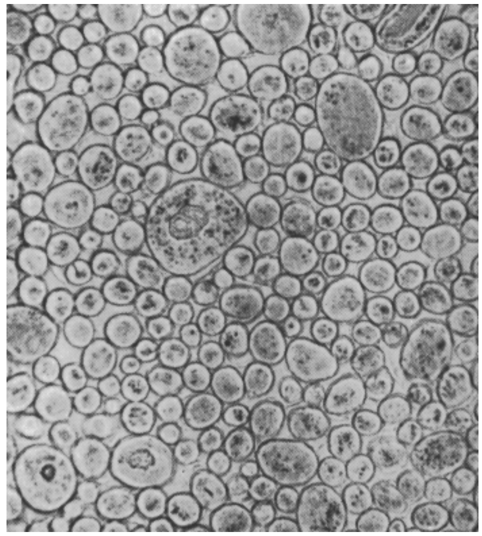

**Figure 13** [8]
Cross-sectional view of camelhair
Magnification 200x

**Figure 14** [8]
Scale patterning of camelhair
Magnification 400x

**Table 5** [8]
Properties of Camelhair Fibers

| ANIMAL | WHOLE MOUNT | | | CROSS-SECTION | | | | SCALE PATTERN | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Profile | Medulla | Pigment Distribution | Contour | Medulla | Cuticle | Pigment Distribution | Base | Mid-Length | Tip |
| CAMEL | ***Fine*** | | | | | | | | | |
| | Regular diameter<br><br>Smooth | None or fragmental | Diffuse<br><br>Sometimes streaky | Circular to oval | Circular | Thin | Sparse and towards the center | Waved mosaic, smooth; near to distant margins | | |
| | ***Coarse*** | | | | | | | | | |
| | Regular diameter<br><br>Smooth | Continuous<br><br>Fine lattice | Some dense<br><br>Streaky | Oval to circular | Oval to circular | Thin | Dense near medulla becoming less dense towards the cuticle | Irregular waved, smooth; near margins | Irregular waved, crenate; near margins | Irregular waved, crenate; near margins |
| | ***Intermediate Thickness*** | | | | | | | | | |
| | Regular diameter<br><br>Smooth | Continuous<br><br>Fine lattice | Some dense<br><br>Streaky | Oval to circular | Oval to circular | Thin | Dense near medulla becoming less dense towards the cuticle | Irregular waved mosaic, smooth; distant margins | | Irregular waved, crenate; near margins |

#### 2.3.4.2 Processing

Very little information can be found in the literature on the actual processing of camelhair. The development of better dyeing techniques for camelhair has helped make it a practical substitute for cashmere. However, it does require an extra processing step because of its light tan coloring; therefore, it must be bleached before dyeing. On the other hand, cashmere is white and does not require bleaching [9]. Unfortunately, no further information on the processing of camelhair is available in the reviewed literature.

#### 2.3.4.3 End Uses

The trend for softer tailoring and lightweight fabrics has helped to maintain the demand for exotic fibers such as camelhair. The greatest interest in camelhair lies in the United States, and is likely to remain in the US market [9]. The US camelhair market accounts for 70% to 75% of fabric production [5].

In production, only the soft under wool or down hair is used in making yarns for apparel applications. The longer fibers, which are removed by a dehairing process, are used in other non-apparel related applications such as rugs and carpeting [9].

Primarily, camelhair is used in woven cloth for men's coatings and jackets. The coarse hair that is up to 37.5 cm in length is used in making felt, carpet backing, cords, low quality rugs, and winter coats that are very warm and completely waterproof. Traditionally, the outer hair is used in bedding because it is said to be beneficial in relieving pain associated with rheumatism and arthritis. The strong springy hair from the camel's mane is used for interlinings [9]. The finer camelhair is usually made into worsted yarn and used for knitwear and light wovens [3]. Some other end products of camelhair are tailored jackets and blazers, as well as sports jackets. Blends of wool and/or silk with camelhair are used for both men's and lady's jacketing [3].

### 2.3.5 Summary of Traditional Animal Fibers

Table 6 [1, 2] displays natural physical properties of wool, mohair, camelhair, and cashmere. Compared to mohair and camelhair, wool can be fine, yet quite strong. Also, mohair and camelhair require less force to deform them than does wool.

Despite the fact that wool is the most widely used protein fiber in manufacturing today, other protein fibers have many attributes as well. Table 7 [3] demonstrates that there are definitely other advantages to mohair, cashmere, and camelhair that wool fibers do not possess. The main advantage that these fibers hold when compared to wool is their softness and tactile appeal. Wool tends to be scratchy and a bit uncomfortable to the bare skin [3].

Figure 15 [1] is a stress-strain curve displaying wool, mohair, and camelhair. This curve shows that both camelhair and mohair have a higher modulus than wool. Camelhair has a breaking extension very similar to that of wool, but is much stronger [1].

**Table 6** [1, 2]
Inherent Physical Properties of Wool, Mohair, Camelhair, and Cashmere

| **Property** | **Unit** | **Wool** | | | **Mohair** | **Camelhair** | **Cashmere** |
|---|---|---|---|---|---|---|---|
| | | **64's** | **56's** | **36's** | | | |
| Fineness | *g/den* | 3.94 | 12.00 | 26.80 | 10.90 | 9.55 | 2.84 |
| Tenacity | *grams/den* | 1.28 | 1.59 | 1.29 | 1.44 | 1.79 | 1.55 |
| Breaking Extension | *%* | 42.50 | 42.90 | 29.80 | 30.00 | 39.40 | 35.6 |
| Initial Young's Modulus | *grams/den* | 26.10 | 24.10 | 33.90 | 39.40 | 33.30 | 36.3 |

**Table 7** [3]
Comparisons of Specialty Hair Fibers

| **Fiber** | **Special Property or Advantage vs. Wool** |
|---|---|
| **Mohair** | Wiry<br>Smooth (large scales)<br>Lustrous<br>Dirt-shedding<br>Long<br>Strong |
| **Cashmere** | Undercoat very fine<br>Buttery soft<br>Rather dull |
| **Camelhair** | Distinctive tan color<br>Thermostatic<br>Makes very warm fabric |

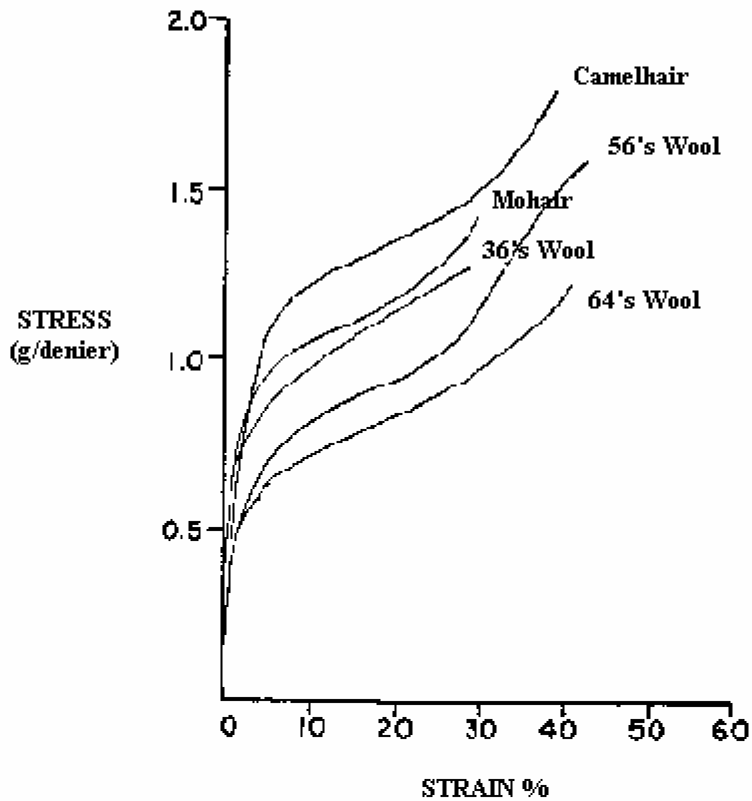


**Figure 15** [1]
Stress-strain curve comparing wool, mohair, and camelhair

**2.3.6 Chiengora (Dog hair)**

There may quite possibly be a wonderful source of material to produce soft and lovely yarns sleeping on your sofa and/or digging up your flower beds [13]. Dog hair was the one fiber spun on this continent before the Spaniards introduced sheep, therefore making the spinning of dog hair an age old art [14]. According to Patty Lee [14], traces of dog hair have been found in yarns of pre-historic Scandinavia and among the North American Navajo Indians [14]. In fact, garments made of dog hair have been worn proudly by the rich and famous for generations [15]. The quality of the yarn produced from dog hair will vary widely depending on what type of hair is used. Generally dogs are two coat animals, with a hairier outer coat, and a soft downy inner coat [13].

Chiengora is the name being used for yarn spun from dog hair. *Chien* is French for dog and *gora* is from angora, the fiber that dog hair most closely resembles. Today, more and more people are discovering the beauty and warmth of hats, mittens, even sweaters made from chiengora. Chiengora yarn can be used just like store-bought yarn [15]. Items made of chiengora yarn are soft and fluffy like angora, incredibly warm, shed water well, and have a lovely color and luster [14]. Chiengora is now considered a luxury fiber along with mohair, cashmere (goat hair), and angora (rabbit hair) [14].

Chiengora is also considered by some to have characteristics that make it more desirable than wool, such as the fact that it produces a yarn that has a lovely ‘halo’ of fuzz, much like mohair or angora, and though it is not as elastic, it is even warmer than wool [15]. This ‘halo’ can be seen in Figure 16 [16], which shows a 2-ply chiengora yarn made from the hair of a Lupa [16].

 **Figure 16** [16] 2-ply chiengora yarn

### 2.3.6.1 Properties

As shown in Figures 17 and 18 [8], the cross-sectional shape of most dog hair is almost circular. The scale patterning along the length of dog hair is regular mosaic and smooth at the root of the fiber, as shown in Figures 19 through 24 [8]. However, towards the tip of the fiber the pattern alternates from diamond petal shaped to wavy pattern.

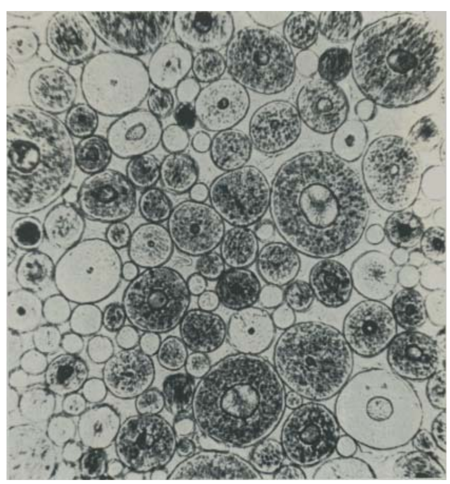

**Figure 17** [8]
Fawn dog fiber cross-section
Magnification 200x

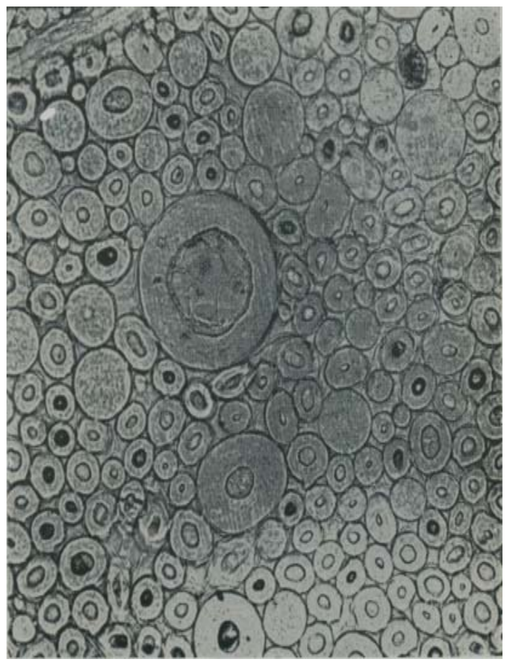

**Figure 18** [8]
White dog fiber cross-section
Magnification 200x

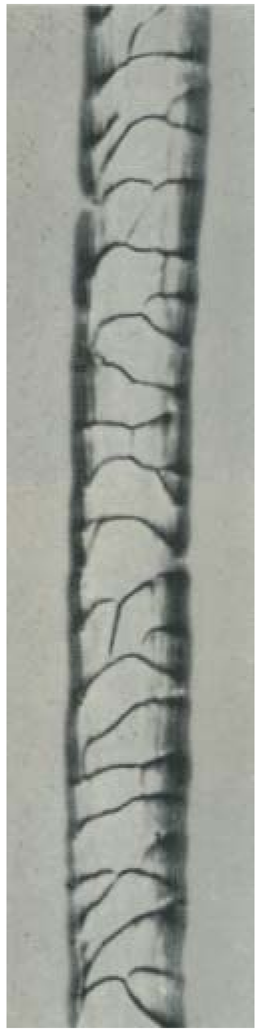

**Figure 19** [8]
Fine dog fiber scale pattern (1)
(Root region)
Magnification 400x

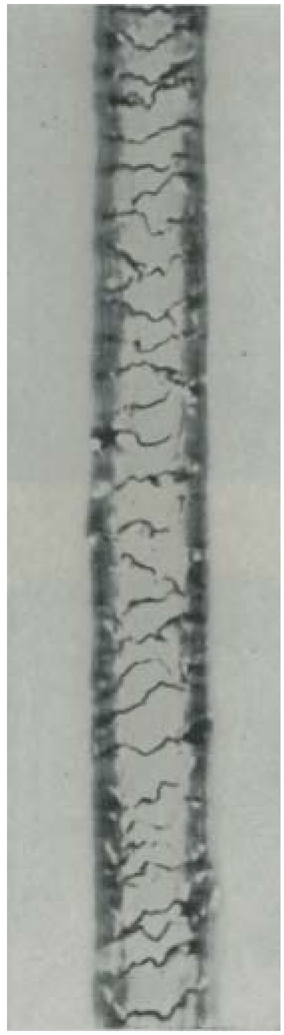

**Figure 20** [8]
Fine dog fiber scale pattern (2)
(Tip region)
Magnification 400x

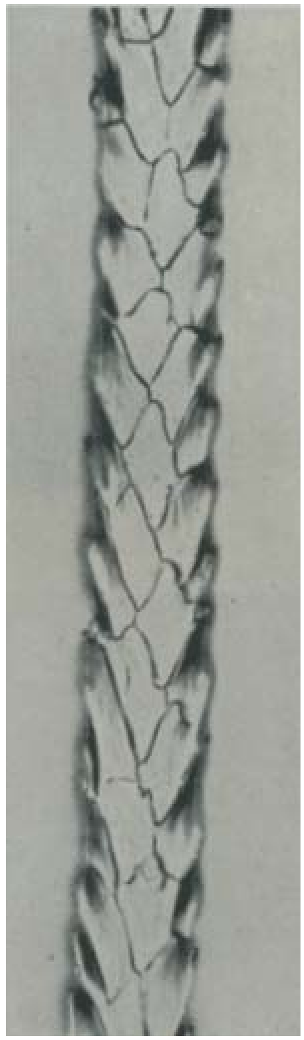

**Figure 21** [8]
Scale pattern along length of fine dog fiber
Magnification 400x

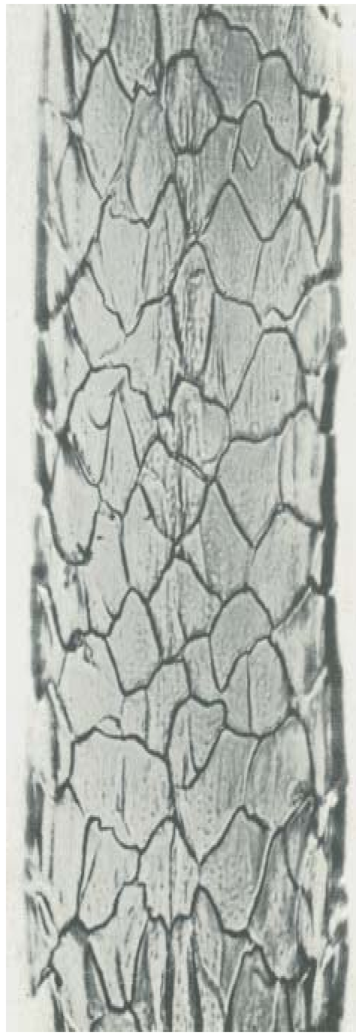

**Figure 22** [8]
Scale pattern along length of coarse dog fiber
Magnification 400x

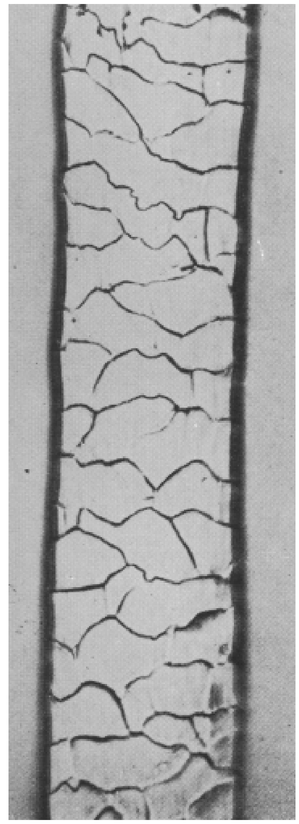

**Figure 23** [8]
Scale pattern along root region of coarse dog fiber
Magnification 400x

**Figure 24** [8]
Scale pattern along tip region of coarse dog fiber
Magnification 400x

The most striking feature of chiengora is its unique fur-like appearance. This furry look and softness is what makes chiengora so reminiscent of angora [14]. A great advantage of chiengora is that it fluffs as it is worn, and thus maintains its new appearance for a long time, making it very durable. Another great property of chiengora is that it sheds very little [14]. Exceptional warmth is another great quality of chiengora. This quality makes it very comfortable to wear in cool to cold temperatures. Because of chiengora's ability to shed water, it insulates well in cold damp weather [14]. Chiengora is heavier and warmer than wool. However, the fibers have little or no crimp, and therefore, little or no elasticity [13].

Dog hair fibers have little cohesion [13]. With some breeds there is a large difference between the outer and inner coats, such as fiber size and color. Even coats that appear to be one color on the dog are actually made of many colors [13]. Many breeds of dogs have spinnable hair including the herding, hound, non-sporting, sporting, terrier, toy breeds, working, and other breeds [14].

A key requirement, as suggested by Patty Lee [14], for spinnable dog hair is that it has a length of at least 2 inches. She suggests that hair between 1 and 2 inches should be mixed with other longer fibers such as wool or silk to make an attractive yarn [14]. Lee [14] states that the softest yarn comes from the combed undercoat of double-coated breeds such as the Collie, Shetland Sheepdog, Old English Sheepdog, and Belgian Sheepdog, just to name a few. Other breeds that are wonderful to use for spinning yarn are the Samoyed, Alaskan Malamute, Siberian Husky, Chow, Newfoundland, Great Pyrenees, Golden Retriever, Akita, and Pomeranian [14]. Clippings from Afghans and Poodles make lovely shiny yarn, much like mohair. The natural shading of these dogs gives a stunning color [14]. Lee [14] recommends using the outer coat of dogs for non-wearables because they tend to be coarse and scratchy [14].

Table 8 [8] summarizes some important characteristics of dog hair. Dog fiber has a somewhat smooth scale pattern, which gives it softness. Also, the diameter of dog fiber seems to vary from the base to the tip of the fiber. The pigment distribution varies from none to dense, and some is streaky. The cross-section of dog hair is almost circular, and it has a fairly thin cuticle.

### 2.3.6.2 Processing

To make a nice yarn, each hair must move freely [14]. It cannot be matted or caught on other hairs. To obtain fiber orientation, the hair should be carded. Carding is a process that opens up the hairs and aligns and separates them. This can be done by using hand cards, as shown in Figure 25 [14]. Lee [14] suggests that cotton cards work best because they have more teeth per inch than wool cards, and do a better overall job on dog hair [14].

**Figure 25** [14] Cotton hand carder

Some spinners do not prepare the dog hair before the spinning process because they feel that not carding allows for a greater variety of colors in the yarn. Not carding the fibers usually results in a variegated yarn, which can be very attractive, but the resulting chiengora yarns will not be as even as when carded fibers are used.

**Table 8** [8]
Properties of Dog Fibers

| ANIMAL | WHOLE MOUNT | | | CROSS-SECTION | | | | SCALE PATTERN | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Profile** | **Medulla** | **Distribution** | **Contour** | **Medulla** | **Cuticle** | **Pigment Distribution** | **Base** | **Mid-Length** | **Tip** |
| **DOG** | ***Fine*** | | | | | | | | | |
| | Regular diameter<br>Scale margins fairly prominent | Some none<br>Some fragmental<br>Some ladder | Varies from none to dense<br>Even or streaky | Almost circular | Some none<br>Some circular & narrow | Fairly thin | Some even<br>Some in large aggregates | Regular mosaic<br>Smooth<br>Near to distant margins | Alternating diamond petal & waved<br>Rippled<br>Near margins | |
| | ***Coarse*** | | | | | | | | | |
| | Regular diameter<br>Scale margins prominent | Continuous<br>Sometimes ladder | Varies from none to dense<br>Even or streaky | Almost circular | Concentric<br>Some narrow | Fairly thin | Some even<br>Some in large aggregates | Regular mosaic<br>Smooth<br>Distant margins | Diamond petal<br>Irregular mosaic | Irregular waved<br>Rippled<br>Near to close margins |

The resulting yarn will be a bit slubby [14]. Some helpful hints on the actual hand spinning of dog hair fiber are listed below [13].

Different ways for preparing the fiber for spinning---

- The locks can be teased open and spun from the fluff
- They can be hand or drum carded and spun in a woolen manner for soft fluffy yarns
- Long silky breeds can be combed and spun worsted
- Use a low tension on the wheel, to work well back from the orifice and to treadle slowly

The next step in the processing of dog hair is preparing a spindle to spin the yarn [14]. A drop spindle, shown in Figure 26 [14], can be used to speed up this process. It consists of a shaft of wood to which a weight is attached at one end. A drop spindle must be perfectly balanced for spinning dog hair [14].

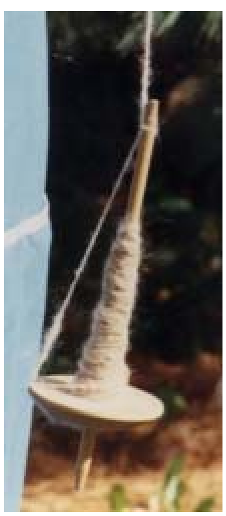

**Figure 26** [14] Drop spindle for spinning chiengora

The spindle must be prepared with about 1-½ yards of an already spun yarn. A small amount of dog hair can be overlapped with the fluffed end of the already spun yarn and pinched, twisted, and drawn until the dog hair begins to form chiengora yarn. The yarn characteristics are greatly determined by the preparation of the fiber, amount of fiber, and the amount of twist [14].

It is best for the hair to be clean and free of chemicals before trying to process. In other words, the dog hair should be obtained just after the animal has been bathed and dried [14]. However, if the collected dog hair is dirty, there are two different views on when to clean the hair, before or after processing. According to Wallace [15], there are spinners who prefer to wash the dog hair after it has been spun into a yarn [15]. If this strategy is taken, carding of the fibers is not necessary, and the natural oil contained in the fibers assists in processing [15].

On the other hand, there are spinners who feel that they get better results by washing the fibers before spinning according to Wallace [15]. Therefore, carding of these freshly washed and dried fibers is necessary before processing. Also, oil should be added to the fibers, which was stripped during the cleaning process. This can be done by adding a small amount of oil to the fibers to make it easier to work with and it also combats static electricity. Any kind of clear oil can be used such as baby oil or mineral oil. Wallace [15] prefers to use mineral oil because it is odorless, clear, and washes out easily. The only stipulation is that the oil should be diluted with water, approximately three parts oil to two parts water. The most efficient way to oil the fibers is using a spray bottle to lightly oil the fibers according to Wallace [15]. The fibers should not be stored with oil. Therefore, oil should not be added any more than a day or two before processing [15].

No matter when the dog fiber is washed, after it has been processed into yarn, it should be washed again. Lee recommends that the chiengora yarn be washed in very warm water and a mild pH balanced detergent for about 1 hour. No scrubbing is necessary. After the yarn has soaked, it should be rinsed in very warm water for about 10 minutes.

Next, one fourth of a cup of vinegar should be added to some very warm water to deodorize the yarn, as well as bring it back to the correct pH. The vinegar also removes any remaining soap. This rinsing and deodorizing process should take from ½ to 1 hour. After this, the yarn should be removed; all excess water squeezed out, and allowed to dry [14]. Once clean and dry, the dog hair is ready to be spun into a beautiful chiengora yarn.

Dog hair can also be blended with other fibers for different visual looks and tactile feel. When blending, spinners recommend lightly carding using the hand or drum cards. It is easier to handle dog hair if it can be sandwiched in between layers of a less static fiber. Using brushed fibers works better than clipped fibers [13].

Dog hair has beautiful shades and variations of color that produce an interesting yarn. Chiengora can be used in its natural state, or it can be dyed [15]. Dog hair accepts dye just as well as wool, though the coarser guard hairs do not accept color well. The dyeing process can be done before or after spinning. If the fibers are dyed before the spinning process, they must be clean. If one chooses to dye the already spun chiengora, the yarn should be in skeins so that the dye can penetrate the fibers easily and evenly. The skeins should be wet before putting them into the dye bath. [15]

Caring for items made from chiengora yarn is surprisingly simple. Small items made are easily hand washed, while large items can be dry-cleaned [14]. Wallace [15] states that chiengora garments can be washed in the same fashion as other fine washables [15]. Hand-washing in lukewarm water with a mild soap or detergent usually works well [15]. Because chiengora is less elastic than wool, garments may tend to lose their shape when wet [15]. To minimize this distortion, Wallace [15] recommends gently squeezing out excess water, rolling the garment up in a towel to remove more excess water, and finally shaping and laying flat to dry. Professional dry cleaning is also an option for chiengora garments [15].

#### 2.3.6.3 End Uses

Chiengora has been used for quite a while in clothing articles as well as accessory items. For some people, making yarn from dog hair is very practical. Dog hair is viewed as a humane, renewable resource and by utilizing that resource, people benefit from something that is usually unwanted, discarded, and free [14]. Dog hair is recyclable and accumulates very quickly during grooming sessions, which makes it very easy to attain [14]. Chiengora yarns are used in a variety of ways such as hand knitting, machine knitting, crocheting, and even as weft yarns by hand weavers. Below in Figure 27 [16] is a chiengora blanket in the process of being woven on a handloom.

**Figure 27** [16]

Chiengora blanket on handloom during weaving process

Currently chiengora yarns are not produced commercially. However, individuals who have interests in chiengora, hand spin the fibers into yarn and then knit or weave the yarn into usable items. The most common clothing articles made from chiengora are sweaters and vests. Scarves, mittens/gloves, shawls, and hats are very common accessories made from dog hair [13]. Decorative items made of chiengora include throw blankets and pillows, wall hangings, and rugs [14]. All dog hair is useable - for something [13].

An assortment of pictures, Figures 28 through 32 [14], of products made from chiengora follows. Figure 33 shows Lee [14] with her hand spinning wheel.

**Figure 28** [14] Chiengora hats, scarves, & mittens

**Figure 29** [14] Chiengora throw blanket

**Figure 30** [14] Chiengora sweater (1)

**Figure 31** [14] Chiengora sweater (2)

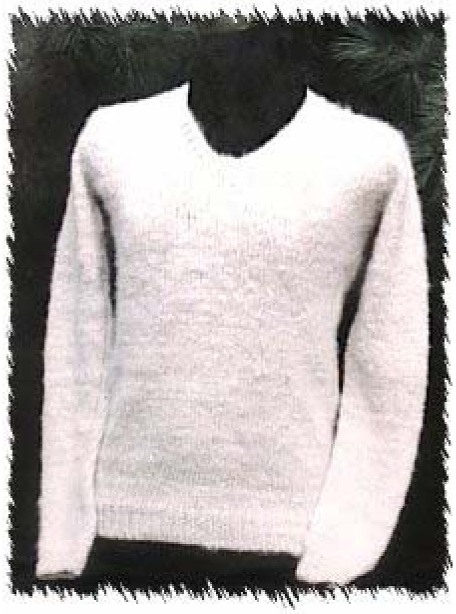

**Figure 32** [14] Chiengora sweater (3)

**Figure 33** [14] Patty Lee hand spinning chiengora

### 2.3.6.4 General Questions on Chiengora

Patty Lee [14] gave a list of the most commonly asked questions about chiengora. Some of these questions and answers are listed below.

*Q. Will I smell like a wet dog if my dog hair sweater gets wet?*

A. The dog smell mainly comes from the oils that keep the hair in good condition; however, if the yarn is properly deodorized there will be no smell. Lee suggests using vinegar for the deodorizing process.

*Q. How much hair does it take?*

A. Lee developed a simple method to estimate the quantity of dog hair needed for many projects. She uses ordinary brown paper grocery bags to measure and store the dog hair. She recommends placing the hair in the bag and pushing down firmly so that you feel the hair push back. This is so that there is no air in the measurement. Below is a chart estimating the amount of hair for certain projects.

| | **Production Method** | | |
|---|---|---|---|
| **Item** | ***Woven*** | ***Knitted*** | ***Crocheted*** |
| *Hat* | N/A | 1/3 of a bag | 2/3 of a bag |
| *Mittens* | N/A | 1/3 of a bag | 2/3 of a bag |
| *Scarf* | 1/3 of a bag | 2/3 of a bag | 1 bag |
| *Vest* | N/A | 1 bag | 1 1/2 bags |
| *Sweater* | N/A | 2 bags | 3 bags |
| *Throw* | 2 bags | 3 bags | 4 bags |
| *Blanket* | 5 bags | too heavy | too heavy |

*Q. Do you have to kill the dog to get hair?*

A. This is definitely not necessary! All naturally obtained animal fibers primarily come from renewable resources. “That’s the beauty and the ‘humanity’ of using animal fibers.”

*Q. What about fleas?*

A. Fleas are attracted to the dog, not the hair. While storing the hair, be sure to store it in a secure fashion so that fleas will not lay eggs in the hair during the storage process.

*Q. How should I store the animal hair?*

A. Storing the hair in tightly closed paper grocery bags works very well. It is recommended that plastic bags with zippers not be used because the hair needs to breath. Also, the hair should be dry before packing it for storage, and should be stored in a dry place.

*Q. What about moths?*

A. Unfortunately, moths love dog hair. Using cedar blocks in with the hair during storage usually deters the moths. [14]

#### 2.3.6.5 Chiengora Personal Testimonials and Professional Opinions

Susan Wallace [15] includes a personal testimonial about chiengora in her book. Wallace knitted her husband a hat made of chiengora and goat hair for him to use during a mountain climbing trip. During the climb, Wallace's husband and the other climbers were caught by a sudden storm, and while the rest of the climbing party's wool hats became encrusted with ice; Wallace's husband's hat remained completely ice free. According to Wallace [15], this incident should definitely convince the non-believers. [15]

According to Dr. George W. Ward [15], Associate Professor of Medicine, Division of Allergy and Clinical Immunology of the University of Virginia, allergies to dogs are far less of a problem than allergies to cats. Ward [15] states that allergies are from the dander shed from the dog's skin, as well as the dog's saliva [15]. Therefore, thorough washing would probably remove most of the allergenic material [15].

Wallace [15] also points out that using dog hair as another fiber source is very economical and environmentally friendly [15]. Dog hair is a totally recyclable material that is usually thrown away. Furthermore, no one has any idea how much pet hair ends up in our landfills and incinerators, or how much electricity is used vacuuming pet hair. Going from garbage to garments or fabric by using the pet hair that would otherwise be discarded is, in fact, a very creative form of recycling. [15]

# 3. EXPERIMENTAL

## 3.1 Materials

### 3.1.1 Animal Fiber – Chiengora

Hair was collected from the following dogs. The number in parenthesis indicates the number of dogs sampled. Though sources were asked to label whether hair was clean or dirty; only hair that was received dirty was used in this research.

- American Eskimo (3)
- Bichon Frise (2)
- Cocka-Poo (2)
- German Shepherd (2)
- Lhasa Apso (2)
- Maltese (2)
- Poodle (Poodle Mix & Sad Poodle) (3)
- Sheep Dog (type not specified) (3)
- Shih Tzu (4)
- Springer Spaniel (2)
- Yorkie (2)
- Golden Retriever (4)
- Schnauzer (4)
- Pomeranian (2)
- Labrador Retriever (2)
- Pekingese (2)
- Westie (2)
- Australian Shepherd (2)

### 3.1.2 Miscellaneous Materials

- Index Cards
- Masking Tape
- Tweezers
- Ruler
- Black Velvet Boards
- Pantyhose
- Ziploc Bags with Labels
- Computer Programs (Excel & SAS)

### 3.1.3 Chemicals

Sodium Carbonate (Soda Ash)
$Na_2CO_3$, dissolved in $H_2O$, formula weight of 24 grams.

Kierlon NB-MFB
BASF, emulsifier & surfactant, formula weight of 25.8 grams/Liter.

### 3.1.4 Equipment

Scouring Machine
Gaston County Laboratory Package Dyeing Machine
Manufacturer: Gaston County, Stanley NC
Low & High Ratio Portions (Low Ratio Portion Used)

Drying Device
GS Blue M Electric Lab Oven
Manufacturer: GS, A unit of General Signal
Model # B2730-Q
Pro-Set II Solid-State Controller, Stabil-Therm Electric Oven
$60^{o}$ Celsius

Sintech 1/S
Manufacturer: MTS Systems Corporation
ASTM D3822-Fiber Tensile (No Slack Cp)
½ inch gauge length

Vibromat ME
Manufacturer: Textechno
ASTM D1577-01-Linear Density; Option C: Vibroscope

Digital Balance
Manufacturer: Mettler Toledo, Switzerland
Model # PB1501; Used for Fiber Measurements
Model # B502-S; Used for Chemical Measurements

## 3.2 Procedures

### 3.2.1 Procedure A: Specimen Collection

Dog hair was solicited from several pet-grooming salons. Hair was collected in Ziploc bags. Groomers were asked to label each bag stating specific dog breed, and whether the sample was clean or dirty.

These specimens were collected once every two weeks from the groomers. Bags labeled as clean were not used in this research. Bags labeled as dirty were split into two equal portions. One portion was scoured before testing and the other portion was tested in its dirty state. Forty-five bags of dog hair were collected from a total of eighteen dog breeds.

### 3.2.2 Procedure B: Scouring Procedure

The dirty dog fibers were weighed using a digital balance before the scouring procedure to allow for weight loss data. To prepare the different samples of dog fibers for the scouring bath, each sample was put into a pantyhose sleeve secured at both ends with a knot and labeled to prevent sample mixing. After placing the sample in the pantyhose sleeve, the sample was weighed again to determine the weight of the pantyhose sleeve.

The scouring was performed in the Gaston County Laboratory Package Dyeing Machine. The scouring machine had a cylindrical metal basket with holes, much like a colander, where the samples were placed. The most efficient way to scour large quantities of samples was to fill the basket full, however, being careful not to overload the basket. Once all samples were in the basket, a metal plate and washer were used to tighten and secure the samples for the vigorous scouring bath. The holes in the basket served the purpose of letting pressurized water shoot through them to agitate and clean the fiber samples. The bath contained Keirlon NB-MFB as the cleaning agent and Sodium Carbonate (Soda Ash) dissolved in water to reduce the amount of suds. The temperature in the bath ranged from 160 to 212 degrees Fahrenheit depending on the stage of the scouring bath.

### 3.2.3 Procedure C: Drying Procedure

After the scouring process, the samples were allowed to dry in an oven (Procedure C) still secured in the pantyhose sleeve. The sleeve containing the fibers was transferred from the scouring bath to a Blue M Lab Oven at 60 degrees Celsius for drying. The samples remained in the oven for twenty-four hours, or until they were bone dry.

Once removed from the dryer, the samples were allowed to recondition for ½ to 1 hour in a standard lab having a temperature of 70 degrees Fahrenheit and a relative humidity of 65%. The dry and conditioned samples still secured in the pantyhose sleeve were weighed again on the same digital balance. The weight of the pantyhose sleeve was subtracted from the final weight to produce an accurate weight loss. The entire scouring procedure required two to two and a half hours.

**3.3 Tests**

**3.3.1 Procedure D: Fiber Length**

ASTM D5103-01, *Standard Test Method for Length and Length Distribution of Manufactured Staple Fiber(s) (Single Fiber Test)*, was used to determine the fiber length measurements. Twenty-five individual length measurements were taken from each sample of clean and dirty hair. This data was used to determine an average fiber length for each dog breed, and also to establish if there was any change in the length after scouring the samples.

**3.3.2 Procedure E: Fiber Size**

The Vibromat was used to determine the size of each fiber. ASTM D1577-01, *Standard Test Methods for Linear Density of Textile Fibers; Option C: Vibroscope, General*, was followed to determine individual fiber sizes. Ten random fibers were measured from each sample, clean and dirty, to determine an individual linear density (denier). Individual fibers tested on the Vibromat were mounted on cards to prepare them for tensile testing (Procedure F).

### 3.3.3 Procedure F: Tensile Testing

Fiber tensile tests were run on the Sintech. ASTM D3822-01, *Standard Test Method for Tensile Properties of Single Textile Fibers*, was used with a gauge length of ½ inch, and a 5 lb load cell. The same ten fibers that were tested on the Vibromat (Procedure E) were used in the tensile tests. The data collected from the Sintech for reporting purposes included tenacity, modulus, and % strain.

## 3.4 Data Analysis

Statistical Analysis Software (SAS) [17] was used to analyze the data. The t-test procedure was used to determine if there was a significant difference in tenacity, size, strain, modulus, and length of clean and dirty fibers in general. The t-test was also used to determine if there was a significant change in the properties of clean and dirty fibers based on dog breed. The means procedure was run to obtain the average and standard deviation of individual properties for all dogs in general and for each dog breed. Finally, a paired t-test was run to determine if there was a significant weight loss between clean and dirty hair for all dogs in general and for individual dog breeds.

# 4. RESULTS & DISCUSSION

## 4.1 Introduction

The purpose of this research is to determine the feasibility of using dog hair in textile products. Traditional properties that determine fiber acceptability for use include fiber length, tenacity, strain, modulus, and fiber size. In this research, the tenacity, linear density, percent strain, modulus, and length of 45 samples of chiengora fibers representing 18 dog breeds are determined for both clean and dirty hair. The average property values for all dogs in general, as well as for individual dog breeds are reported in Tables 9a and 9b. Also listed in Tables 9a and 9b are the tensile properties of four traditional animal hair fibers, wool, mohair, cashmere, and camelhair. It is believed that properties of the traditional fibers are given for clean fibers.

Chiengora properties will be compared to traditional animal hair fibers used in textile products to determine acceptability for use. Since fibers will be received in a dirty state but will require cleaning at some time during processing, the effect of laundering the fibers on their physical properties will be assessed. At this stage in the research, the final goal is to pinpoint 5 to 7 dog breeds that might provide acceptable chiengora fibers that will be considered for further commercial processing into yarns and/or fabrics.

## 4.2 Effect of Cleaning Hair

As seen in Table 10, statistical results show a significant difference between clean and dirty chiengora for tenacity, strain, and length with greater than 95% confidence, $Pr > | t |$ less than 0.05, and denier with greater than 90% confidence, $Pr > | t |$ less than 0.10. There was no significant difference between the modulus of clean and dirty hair.

**Table 9a**

Tensile Data for All Dog Breeds and Traditional Animal Fibers

| Dog Breed | Tenacity g/denier | | Strain % | | Modulus g/denier | |
|---|---|---|---|---|---|---|
| | Clean | Dirty | Clean | Dirty | Clean | Dirty |
| **All Breeds** | 1.886 | 2.147 | 64.149 | 72.500 | 15.315 | 15.661 |
| **American Eskimo** | 1.726 | 2.226 | 60.512 | 80.118 | 14.499 | 14.804 |
| **Bichon** | 1.536 | 1.855 | 57.778 | 68.392 | 13.689 | 13.389 |
| **Cocka-Poo** | 1.699 | 2.117 | 66.044 | 67.907 | 13.841 | 16.092 |
| **German Shepherd** | 1.958 | 2.269 | 66.167 | 76.239 | 15.094 | 15.731 |
| **Lhasa** | 1.759 | 2.096 | 63.494 | 74.216 | 14.991 | 15.401 |
| **Maltese** | 1.910 | 1.923 | 70.685 | 66.637 | 13.462 | 14.141 |
| **Poodle** | 2.016 | 1.917 | 71.634 | 73.459 | 14.010 | 13.545 |
| **Sheep Dog** | 1.828 | 2.065 | 65.014 | 68.201 | 14.271 | 15.356 |
| **Shih Tzu** | 1.778 | 1.864 | 58.210 | 64.939 | 16.176 | 14.834 |
| **Springer Spaniel** | 2.149 | 2.667 | 72.533 | 96.368 | 16.009 | 14.315 |
| **Yorkie** | 1.500 | 2.069 | 53.634 | 74.223 | 14.680 | 14.537 |
| **Golden Retriever** | 2.222 | 2.154 | 77.186 | 72.180 | 14.708 | 15.833 |
| **Schnauzer** | 1.799 | 2.325 | 56.326 | 59.932 | 16.533 | 21.475 |
| **Pomeranian** | 1.710 | 2.143 | 62.616 | 68.328 | 14.374 | 17.231 |
| **Labrador Retriever** | 1.713 | 2.277 | 57.714 | 70.053 | 15.125 | 17.437 |
| **Pekingese** | 2.231 | 2.196 | 68.708 | 69.087 | 16.400 | 16.511 |
| **Westie** | 1.970 | 2.190 | 64.807 | 76.433 | 15.213 | 13.868 |
| **Australian Shepherd** | 2.342 | 2.504 | 59.984 | 96.612 | 22.716 | 13.871 |
| **Wool** | 1.59 | | 42.9 | | 24.1 | |
| **Mohair** | 1.44 | | 30.0 | | 39.4 | |
| **Cashmere** | 1.55 | | 35.6 | | 36.3 | |
| **Camelhair** | 1.79 | | 39.4 | | 33.3 | |

**Table 9b**
Physical Properties of All Dog Breeds and Traditional Animal Fibers

| Dog Breed | Linear Density *g/9000m* | | Length *cm* | |
|---|---|---|---|---|
| | Clean | Dirty | Clean | Dirty |
| **All Breeds** | 29.66 | 28.19 | 5.76 | 5.55 |
| **American Eskimo** | 26.90 | 31.20 | 5.30 | 4.50 |
| **Bichon** | 28.99 | 27.47 | 5.20 | 5.50 |
| **Cocka-Poo** | 28.72 | 24.20 | 5.30 | 5.10 |
| **German Shepherd** | 30.26 | 29.27 | 7.30 | 7.40 |
| **Lhasa** | 38.36 | 32.19 | 7.10 | 6.30 |
| **Maltese** | 25.94 | 23.86 | 7.31 | 7.42 |
| **Poodle** | 25.72 | 23.10 | 4.90 | 4.40 |
| **Sheep Dog** | 32.57 | 27.55 | 5.40 | 4.90 |
| **Shih Tzu** | 24.74 | 24.65 | 5.30 | 3.90 |
| **Springer Spaniel** | 32.71 | 27.71 | 7.90 | 8.30 |
| **Yorkie** | 31.25 | 27.31 | 9.40 | 8.90 |
| **Golden Retriever** | 32.33 | 30.42 | 6.50 | 7.00 |
| **Schnauzer** | 28.91 | 27.14 | 3.90 | 4.10 |
| **Pomeranian** | 24.54 | 24.28 | 6.70 | 6.70 |
| **Labrador Retriever** | 33.78 | 31.60 | 4.10 | 4.00 |
| **Pekingese** | 27.55 | 26.47 | 4.40 | 4.60 |
| **Westie** | 23.10 | 26.57 | 3.90 | 3.60 |
| **Australian Shepherd** | 42.30 | 46.12 | 6.30 | 6.30 |
| **Wool** | 12.0 | | 10.16 | |
| **Mohair** | 10.9 | | 11.5 | |
| **Cashmere** | 2.84 | | 3.9 | |
| **Camelhair** | 9.55 | | 12.5 | |

**Table 10**
Significance Between Clean and Dirty Chiengora (All Breeds Tested)

| Variable | Condition | Mean | Standard Deviation | T-Value | Pr > ∣ t ∣ |
|---|---|---|---|---|---|
| **Tenacity** | Clean<br>Dirty<br>Difference | 1.886<br>2.147<br>-0.261 | 0.586<br>0.639<br>0.613 | -6.390 | <.0001 |
| **Linear Density** | Clean<br>Dirty<br>Difference | 29.66<br>28.19<br>1.47 | 12.14<br>11.71<br>11.93 | 1.84 | 0.07 |
| **Strain** | Clean<br>Dirty<br>Difference | 64.149<br>72.500<br>-8.352 | 18.083<br>18.007<br>18.045 | -6.940 | <.0001 |
| **Modulus** | Clean<br>Dirty<br>Difference | 15.315<br>15.661<br>-0.345 | 5.093<br>6.352<br>5.757 | -0.900 | 0.369 |
| **Length** | Clean<br>Dirty<br>Difference | 5.76<br>5.55<br>0.22 | 1.40<br>1.55<br>1.48 | 2.21 | 0.03 |

Overall there was a 3.9% increase in the length of dog hair due to the cleaning procedures. This implies that washing and drying removed some or all of the natural crimp in the fibers. Also, there was a 12.0% reduction in strength due to cleaning. This is not surprising since wool fibers are also weaker when wet. Trotman [18] states two different scenarios to explain why wool fibers become weaker when wet. Trotman's first explanation of wool's wet behavior is caused by the moisture reducing the binding force between the salt linkages by introducing a dielectric film between the positive and negative charges [18]. Trotman's [18] other explanation for wool's weaker wet behavior suggests that this decrease in wet strength is due to greater swelling of the fiber at high pH [18]. According to Trotman [18], the cystine link also has a profound effect upon the mechanical properties of the fiber.

The disulphide bond is covalent and not very sensitive to pH, but there are a number of reagents, which can break it down. Water can bring about hydrolysis, especially when in the form of steam with the formation of sulphenic acid groups, therefore, the action of alkalis on the disulphide bond is complex and accompanied by the formation of inorganic sulphides. The bond is severed, but new cross-links are formed [18].

There was a 5.2% increase in linear density, implying that the fibers were coarser after washing. Possible explanations of this occurrence could be swelling in the channel or core of the dog fibers that occurred during the scouring bath due to the presence of soda ash, or that some moisture still remained in the fiber after washing. This would be very similar to how cotton and wool react to soda ash in a scouring bath. However, if there was moisture remaining in the fiber, one would expect to see an increase in percent strain, not an 11.5% decrease. Moisture acts like a lubricant and would cause the fiber to be more flexible. Though there is a slight insignificant decrease in modulus, it is not enough to indicate that the clean fibers are more flexible than the dirty fibers.

However, from Table 11, it can be seen that not all dog fibers are equally affected by laundering. The difference in length of clean and dirty fibers was significant at greater than 95% for all dog breeds. However, for 8 of the 18 dogs, or 44.4%, length was the only property significantly affected. Also, hair from some dog breeds was only mildly affected, having only one property other than length significantly affected at 95% or better. This was the case for 4 of the 18, or 22.0%, of the dog breeds.

Only 6 of the 18 dogs, or 33.0%, appeared to be highly affected, having more than two of the properties affected by cleaning. These dogs were the Yorkie, Pomeranian, American Eskimo, and the Australian Shepherd, in which three properties were affected. The Springer

Spaniels and Labrador Retrievers were dogs in which 4 of the 5 properties were affected by laundering.

Overall, the significant change in some critical properties due to the cleaning procedures does mean that special care should be taken in laundering dog hair, and products made from chiengora. Since properties like strength and length affect processibility of fibers, consideration should be given to when laundering should occur, before or after processing into a yarn or fabric. There is an increase in length after cleaning, and generally longer fibers make better yarns. However, if the increase in length is due to a decrease in crimp, the clean fiber will have less cohesion and therefore be harder to process. Also, weaker fibers are harder to process. These concerns might lead one to conclude that it is best to process the fiber while dirty and then wash it in either the yarn or fabric state. The environment in which employees would be asked to work must balance this conclusion. However, though there is a significant difference between clean and dirty fibers, since comparisons will be made with traditional hair fibers that are clean, future discussions will be based on clean chiengora only.

**4.3 Fiber Strength Data**

Table 9a lists the tenacities of all dog breeds tested during this research, as well as the tenacities of the four traditional animal fibers, wool, mohair, cashmere, and camelhair, discussed earlier in Section 2-Literature Review. The overall tenacity for chiengora as reported in Table 9a is 1.886 g/denier. Thus the average tenacity for chiengora fibers is 5.0% greater than that of the strongest traditional animal hair fiber, camelhair.

**Table 11**

Significance Between Clean and Dirty Chiengora (Breed Specific)

| Dog Breed | Pr > \| t \| | | | | |
|---|---|---|---|---|---|
| | **Tenacity** (g/denier) | **Strain** (%) | **Modulus** (g/denier) | **Linear Density** (g/9000 m) | **Length** (cm) |
| **American Eskimo** | <.0001 | 0.0004 | 0.777 | 0.12 | <.0001 |
| **Bichon Frise** | 0.078 | 0.094 | 0.805 | 0.65 | <.0001 |
| **Cocka-Poo** | 0.074 | 0.748 | 0.178 | 0.12 | <.0001 |
| **German Shepherd** | 0.126 | 0.109 | 0.597 | 0.76 | <.0001 |
| **Lhasa Apso** | 0.148 | 0.046 | 0.833 | 0.11 | <.0001 |
| **Maltese** | 0.959 | 0.352 | 0.672 | 0.54 | <.0001 |
| **Poodle** | 0.420 | 0.685 | 0.479 | 0.29 | <.0001 |
| **Sheep Dog** | 0.150 | 0.460 | 0.406 | 0.22 | <.0001 |
| **Shih Tzu** | 0.408 | 0.029 | 0.158 | 0.97 | <.0001 |
| **Springer Spaniel** | 0.002 | 0.001 | 0.215 | 0.01 | <.0001 |
| **Yorkie** | 0.001 | 0.001 | 0.920 | 0.35 | <.0001 |
| **Golden Retriever** | 0.571 | 0.140 | 0.103 | 0.50 | <.0001 |
| **Schnauzer** | 0.013 | 0.257 | 0.064 | 0.59 | <.0001 |
| **Pomeranian** | 0.005 | 0.264 | 0.034 | 0.91 | …… |
| **Labrador Retriever** | 0.0001 | 0.029 | 0.060 | 0.60 | <.0001 |
| **Pekinese** | 0.823 | 0.904 | 0.942 | 0.57 | <.0001 |
| **Westie** | 0.068 | 0.004 | 0.124 | 0.16 | <.0001 |
| **Australian Shepherd** | 0.201 | <.0001 | 0.001 | 0.22 | …… |

When examining the clean dog fiber data, the breeds with the highest tenacity in decreasing order were Australian Shepherd, Pekingese, Golden Retriever, Springer Spaniel, and Poodle. These tenacities range from 2.342 g/denier (Australian Shepherd) down to 2.016 g/denier (Poodle). The traditional animal hair fiber that has the highest tenacity is camelhair, which has a tenacity of 1.79 g/denier. Of the 18 breeds tested, 10 or 56.0% of them had tenacities that exceeded that of camelhair. The average tenacity for the top 10 dog breeds was 2.04 g/denier. Thus, the top 10 dogs based on tenacity had fiber strengths that were on the average 14.0% stronger than camelhair. Sixteen of the 18 dogs tested (or 89.0%) had hair that was stronger than cashmere (1.55 g/denier) or wool (1.59 g/denier). All dog breeds had hair stronger than mohair (1.44 g/denier). The Yorkie breed has the lowest tenacity value, 1.5 g/denier, of the dog breeds tested.

Figure 34 displays the tenacity values for the dog breeds tested as well as wool, cashmere, camelhair, and wool. The chart is divided into groups based on the tenacity ranges displayed in the figure's legend. Ranges are picked to correspond with traditional animal hair fibers. Clearly this shows that dog fibers have strengths similar to or better than those of the traditional protein fibers used in processing today. Also one can conclude that any dog to the left of wool in Figure 34 will have hair with adequate strength for commercial processing.

**4.4 Fiber Linear Density Data**

Table 9b lists the linear densities of all dog breeds tested during this research, as well as the linear densities of the four traditional animal fibers, wool, mohair, cashmere, and camelhair, discussed earlier in Section 2-Literature Review. Generally, the larger the fiber size of the dog hair tested, the higher the tenacity value, as is true for mohair and camelhair, as well as about 50.0% of the dog breeds tested. The overall linear density for chiengora as

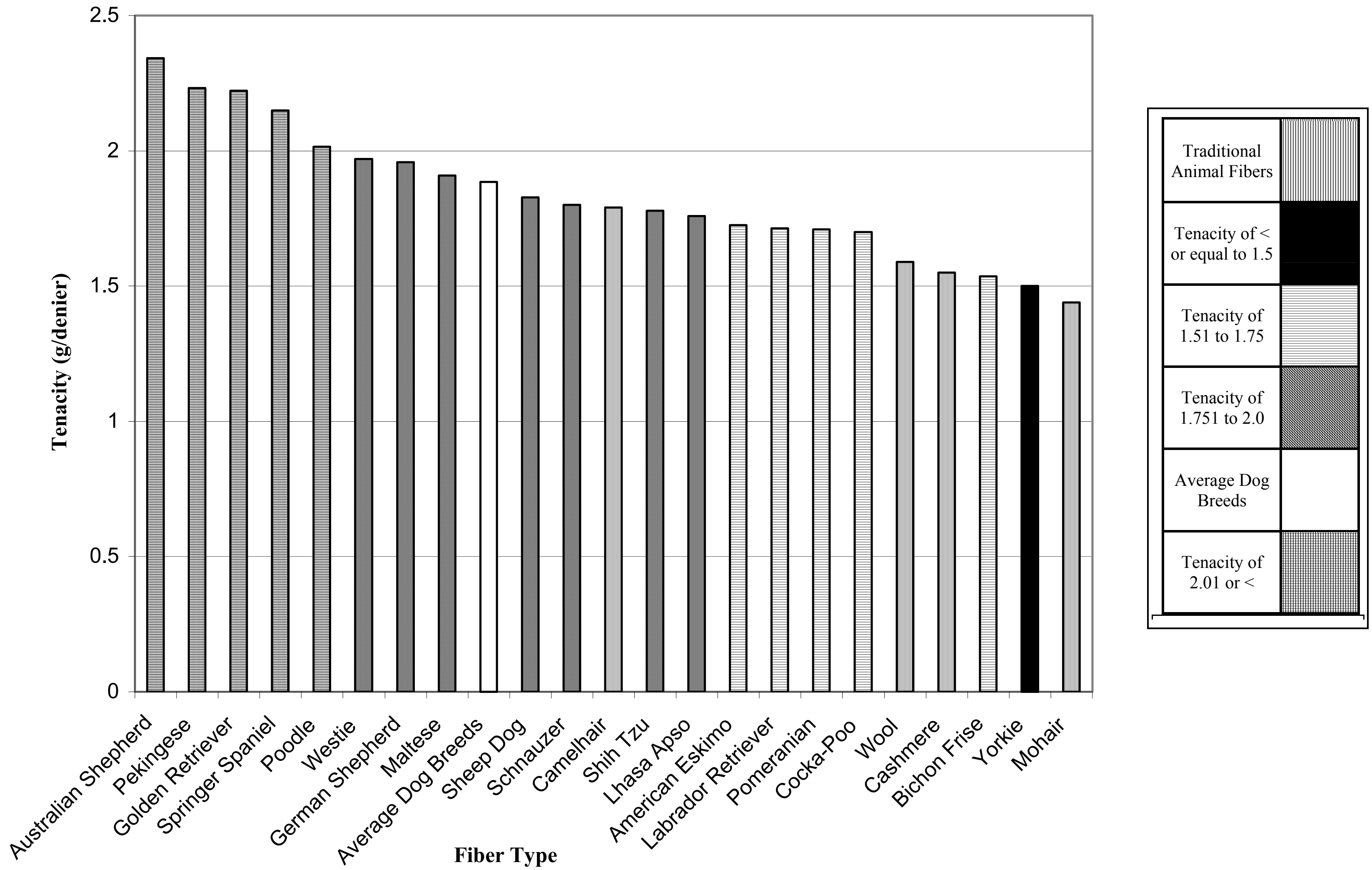


**Figure 34**
**Dog & traditional animal fiber tenacity**

reported in Table 9b is 29.66 denier. Thus the average linear density for chiengora fibers is 59.5% greater than that of wool. This means that dog hairs are much coarser than traditional animal hair fibers.

When examining the clean data for the dog breeds tested, the breeds with the highest linear density in decreasing order were Australian Shepherd, Lhasa Apso, Labrador Retriever, Springer Spaniel, and Sheep Dog. These linear densities range from 42.30 denier (Australian Shepherd) down to 32.57 denier (Sheep Dog). The Australian Shepherd breed having the largest linear density accordingly has the highest tenacity. The traditional animal hair fiber that has the highest linear density is wool, which has a linear density of 12.0 denier.

Of the 18 breeds tested, all of them had linear densities that exceeded that of wool. The five breeds having the lowest linear density were Maltese, Poodle, Shih Tzu, Pomeranian, and Westie. The average linear density for these five breeds is 24.81 denier. These fiber breeds were 52.0% coarser than wool, the coarsest traditional animal hair fiber. However, these five breeds also have strengths that are equal to or better than traditional hair fibers used in textile products. The Westie breed has the lowest linear density, 23.10 denier, of the dog breeds tested. Despite the smaller size of the Westie fiber, its tenacity, 1.97 g/denier, is admirable, and stronger than all the traditional animal fibers. However, the linear density of the Westie breed is still 48.0% higher than wool. Finer fibers are more easily converted into yarn because they require less twist. The coarseness of dog fibers could cause one to question the feasibility of commercially converting them into yarns.

Generally in textile processing it is desirable to have fibers with the high aspect ratio, for example, high length to width ratio. Fibers with a high aspect ratio tend to be more flexible and thus bend more easily. Dog fibers, on the average, are shorter and much coarser than wool. Thus they will have a lower aspect ratio that may present a problem during conversion to yarn. However, it must be remembered that these fibers are currently being handspun into yarns and made into fabrics.

Figure 35 displays the linear densities for the dog breeds tested as well as wool, cashmere, camelhair, and wool. The figure is divided into groups based on the linear density ranges shown in the figure's legend. Ranges are picked to correspond with traditional animal hair fibers. This figure shows that dog fiber has a much larger linear density than any of the traditionally used animal fibers. These larger fiber sizes should definitely be taken into account when determining suitability for processing methods.

**4.5 Fiber Strain**

Table 9a lists the percent strains of all dog breeds tested during this research, as well as the percent strains of the four traditional animal fibers, wool, mohair, cashmere, and camelhair, discussed earlier in Section 2-Literature Review. The overall percent strain for chiengora as reported in Table 9a is 64.149%. The average percent strain for chiengora fibers is 20.3% greater than that of wool. Therefore, dog fibers elongate much more than traditional animal fibers before breaking.

When examining the clean data for the dog breeds tested, the breeds with the highest percent strain in decreasing order were Golden Retriever, Springer Spaniel, Poodle, Maltese, and Pekingese. These percent strains range from 77.186% (Golden Retriever) down to 68.708% (Pekingese). The traditional animal hair fiber that has the highest percent strain is wool, which has a percent strain of 42.9%. Of the 18 breeds tested, all of them had percent strains that exceeded that of wool. All dog breeds tested had hair that was more extensible than cashmere (35.65%), camelhair (39.4%), and mohair (30.0%).

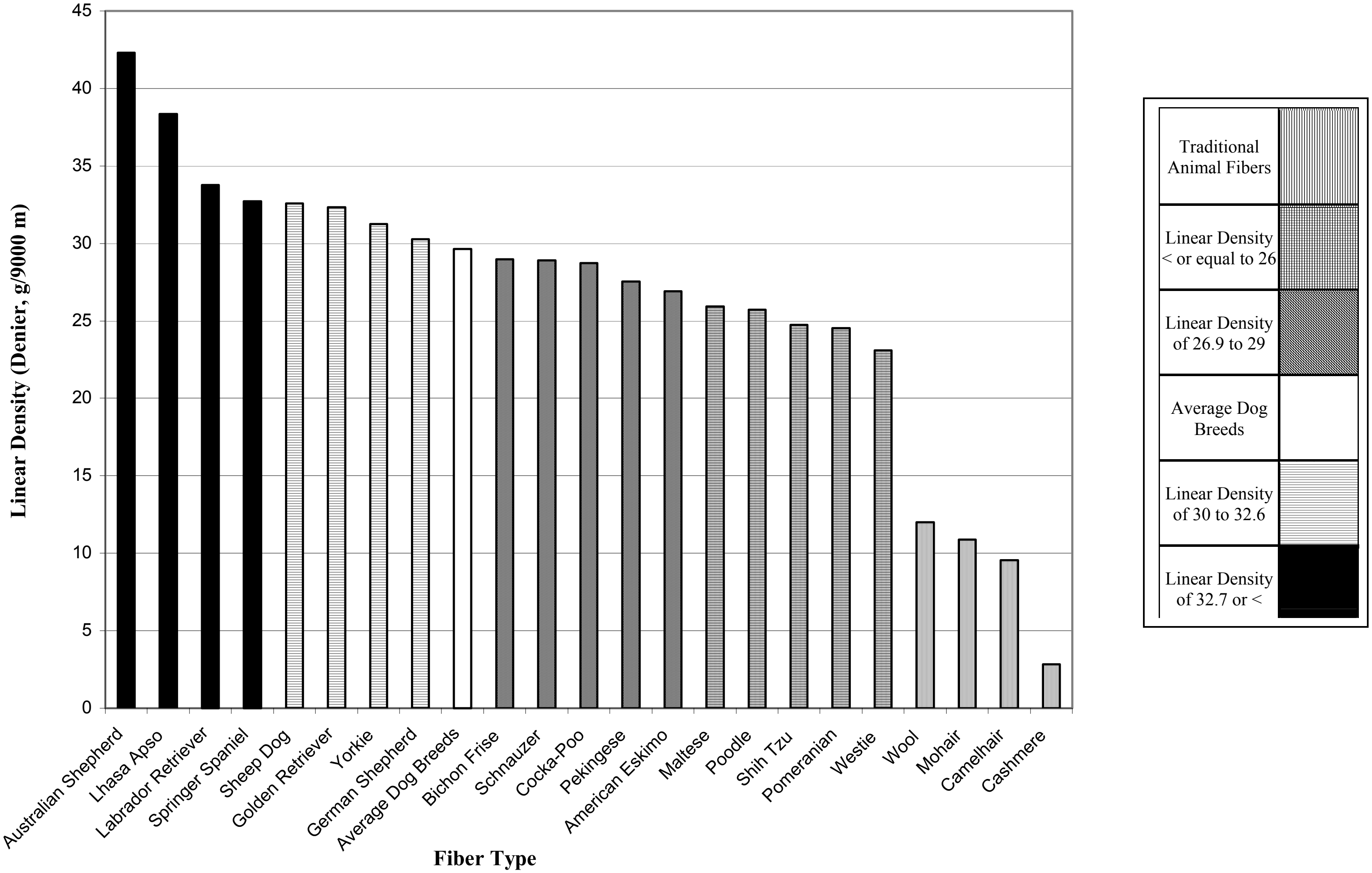


**Figure 35**
**Dog & traditional animal fiber linear density**

These high extension values as well as high tenacity values show that dog fibers can absorb a high amount of energy, which is important when considering abrasion resistance, crease recovery, and resilience [1]. These higher percent strain values become important during the processing of fibers into yarns. The conversion of fibers into yarn puts stress on each individual fiber; therefore, fibers that elongate easily before breaking will process with less difficulty. The finer dog fibers, Westie, Shih Tzu, and Schnauzer, have a lower elongation than the thicker fibers, which correlates directly with the behavior of wool, mohair, cashmere, and camelhair.

Figure 36 displays the percent strain values for the dog breeds tested as well as wool, camelhair, cashmere, and mohair. The figure is divided into groups based on the percent strain ranges displayed in the figure's legend. Ranges are picked to correspond with traditional animal hair fibers. This data shows that when compared to the traditionally used animal fibers, dog fiber has a much higher percent strain. From this, one may conclude that these high extension values for dog fiber prove its suitability for yarn processing.

**4.6 Fiber Modulus**

Table 9a lists the modulus of all dog breeds tested during this research, as well as the modulus of the four traditional animal fibers, wool, mohair, cashmere, and camelhair, discussed earlier in Section 2-Literature Review. The modulus value shows what force is needed to deform the fiber. When comparing the modulus values of the dog breeds tested to traditional animal fibers, the dog fibers have much lower modulus values, meaning that they deform at a quicker rate than do wool, mohair, cashmere, and camelhair. The overall modulus for chiengora as reported in Table 9a is 15.315 g/denier. Thus, wool, having the

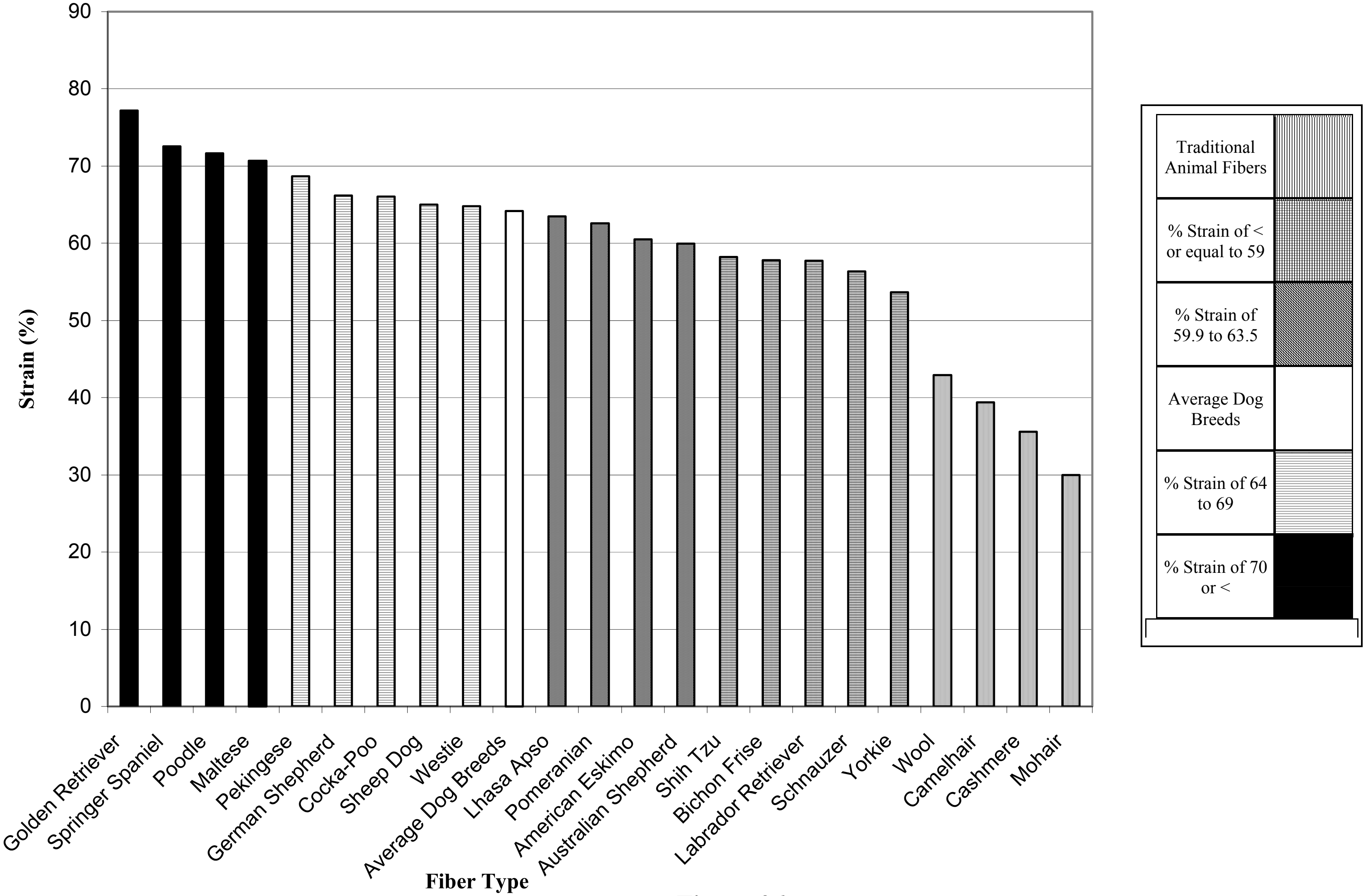


**Figure 36**
**Dog & traditional animal fiber strain**

lowest modulus of the traditional fibers, has a modulus that is 36.5% greater than the average dog hair.

When examining the clean data for the dog breeds tested, the breeds with the highest modulus in decreasing order were Australian Shepherd, Schnauzer, Pekingese, Shih Tzu, and Springer Spaniel. These modulus values range from 22.716 g/denier (Australian Shepherd) down to 16.009 g/denier (Springer Spaniel). The traditional animal hair fiber that has the highest modulus is mohair, which has a modulus of 39.4 g/denier. Of all 18 dog breeds tested, none of the dog hairs had moduli that were within 10.0% of the modulus of mohair, cashmere, or camelhair. Wool's modulus, 24.10 g/denier, is very similar to the Australian Shepherd breed's modulus of 22.716 g/denier. The Maltese breed has the lowest modulus value, 13.462 g/denier, of the dog breeds tested. This data shows that dog fibers are not as stiff as the traditional animal fibers, therefore, they have a lower resistance to deformation.

When examining modulus values for specific fibers, one must keep in mind the intended end use for the fiber or yarn. In some instances, a fiber with a low modulus would be preferred. However, when considering a fiber for a protective garment, such as a bullet proof vest, a fiber with a high modulus is unquestionably preferred. Cotton fibers, with an average modulus of about 4.0 g/denier [20], are commonly used in apparel applications. When comparing cotton's modulus to the modulus of the dog fiber tested, 15.0 g/denier, it would show dog fiber should perform just as well as cotton during processing if not better. Therefore, the modulus values of dog fibers would prove to be adequate in the correct circumstance(s).

Figure 37 displays the modulus values for the dog breeds tested as well as wool, camelhair, cashmere, and mohair. This modulus information should be taken into account

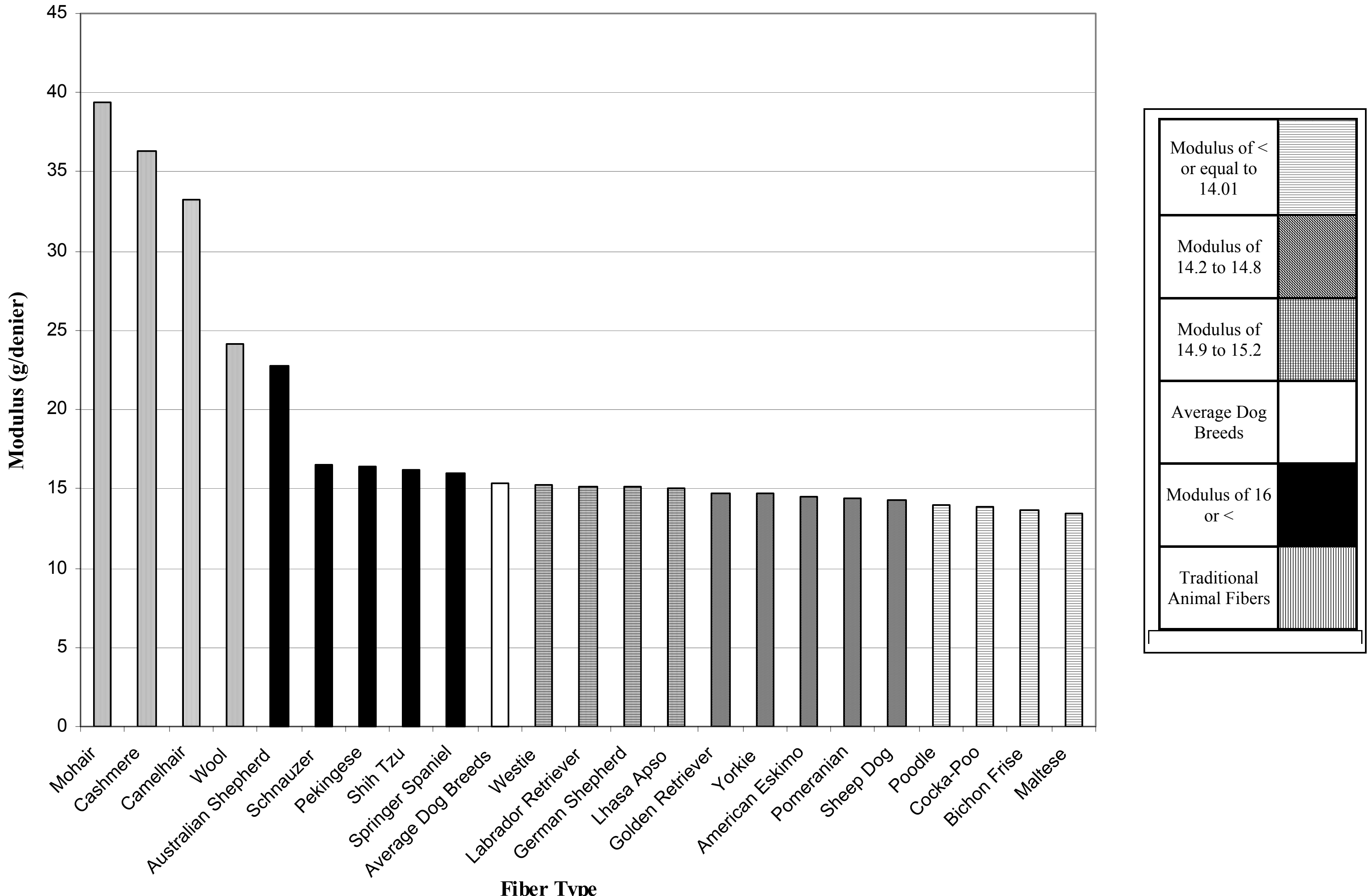


**Figure 37**

**Dog & traditional animal fiber modulus**

when determining end use feasibility. The figure is divided into groups based on the modulus ranges listed in the figure's legend. Ranges are picked to correspond with traditional animal hair fibers. This data shows that dog fiber has a considerably lower modulus than do the traditionally used animal fibers in textile processing. The Australian Shepherd breed is the only dog that closely matches the traditional animal fibers in modulus. This factor could make some yarn processing techniques with dog fiber more difficult than with traditional animal fibers.

**4.7 Fiber Length**

Fiber length is a very important factor when choosing the best processing and production method for fibers. Generally, the longer fibers are easier to spin, where the shorter fibers are mainly used for short staple fiber production and nonwoven production.

Table 9b lists the fiber lengths of all dog breeds tested during this research, as well as the lengths of the four traditional animal fibers, wool, mohair, cashmere, and camelhair. The overall fiber length for chiengora as reported in Table 9b is 5.76 cm. Thus the average length for chiengora fibers is 56.0% lower than that of camelhair.

When examining the clean data for the dog breeds tested, the breeds with the longest fiber lengths in decreasing order were Yorkie, Springer Spaniel, Maltese, German Shepherd, and Lhasa Apso. These fiber lengths range from 9.4 cm (Yorkie) down to 7.1 cm (Lhasa Apso). The traditional animal hair fiber that has the longest length is camelhair, which has a length of 12.5 cm. All dog breeds had hair longer than cashmere (3.9 cm). Despite cashmere's short length of 3.9 cm, it processes with no major problems. Today there is such a variety of processing methods, that fiber length is not as much of an issue as it was several years ago.

When evaluating the fiber length data, there are some dog breeds that would seem to fit well in the short staple fiber production method where the typical processing length ranges from 2.5 to 5.1 cm. The Poodle, Schnauzer, Labrador Retriever, Pekingese, and Westie breeds have an average length of 4.0 cm, which would process well as short staple fibers. Yorkie, the breed with the longest fibers, with an average fiber length of 9.4 cm should process quite as well as any of the traditional animal fibers. In nonwoven production, short fibers, even fibers less than 1mm, are suitable. However, fibers as long as 6.0 inches can also be used in nonwoven production methods. Therefore, fiber length is not an issue when using a nonwoven production method. This means that basically all dog fibers would process well into a nonwoven product.

Figure 38 displays the fiber lengths for the dog breeds tested as well as wool, cashmere, camelhair, and wool. The figure is divided into groups based on the length ranges shown in the figure's legend. Ranges in Figure 38 are picked to correspond with traditional animal hair fibers. This data shows that the length of dog fiber is slightly less than that of the traditionally used animal fibers. However, there is not a dog fiber included in the breeds tested that is shorter than 3.0 centimeters. Three centimeters is a gracious length when considering nonwoven production methods. Also, the dog fiber lengths obtained during this research would prove to be suitable for short staple yarn production methods. The most ideal processing method for dog fiber when considering length would need to be explored.

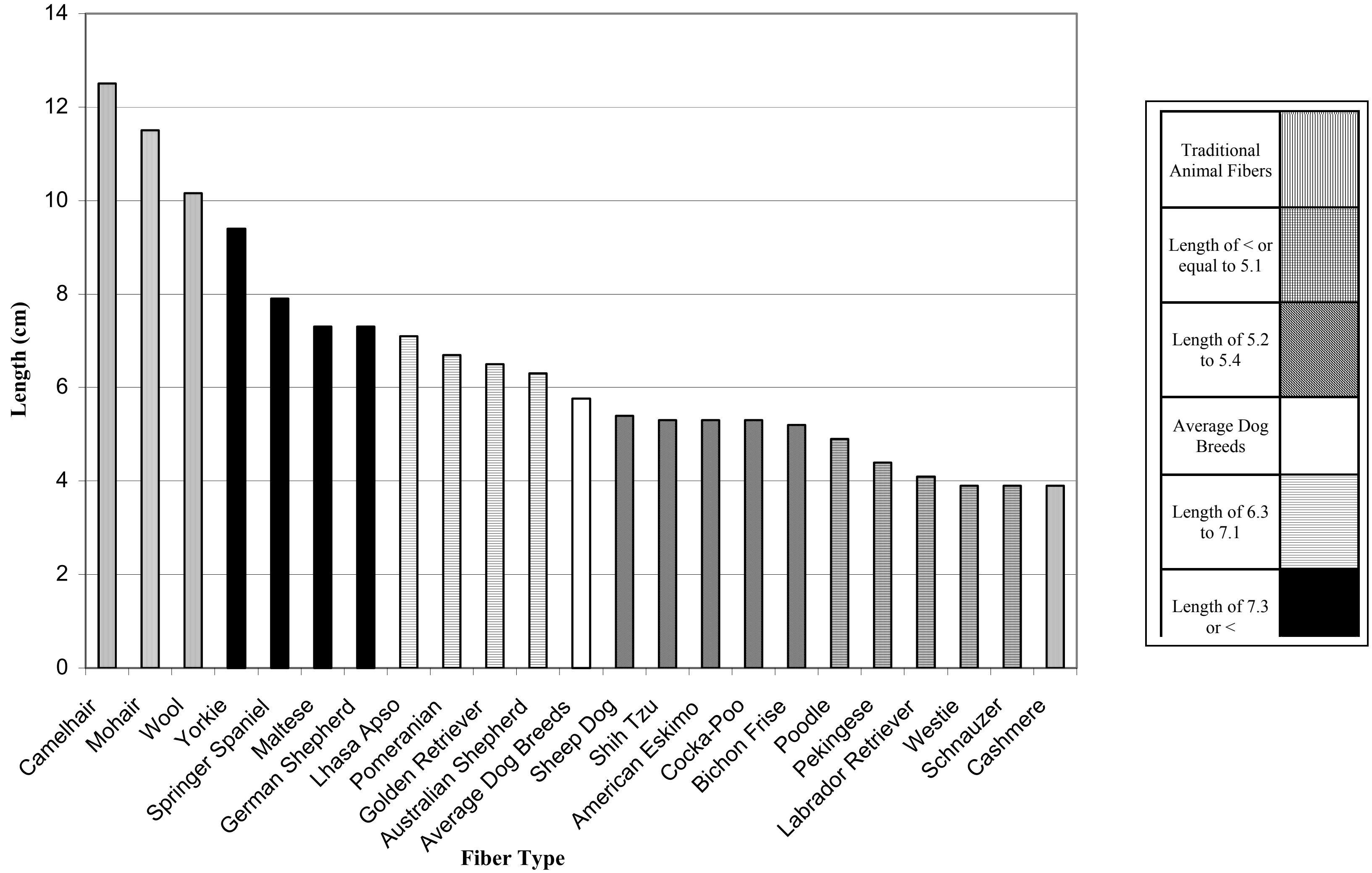


**Figure 38**
**Dog & traditional animal fiber length**

# 5. CONCLUSIONS

As stated earlier, the main objective of this research is to determine the feasibility of using dog hair in conventional textile products. The properties that were the main focus during the research were tenacity, linear density, modulus, and percent strain of dog hair.

From the results of the study, many conclusions can be made based on the properties mentioned above. The average dog hair had a tenacity of 1.89 g/denier. When examining the tenacity of dog fiber as compared to that of the traditionally used animal fibers, dog hair proved to be 5% stronger than the strongest traditional animal fiber, camelhair. With this result, using dog fibers in textile production would prove no problem. The average length of chiengora was 5.8 cm. The length of the dog fibers tested was 45.4% shorter than that of the traditional animal fibers. The average linear density of chiengora was 29.7 denier. It was determined that the linear density of the dog breeds tested was overall 59.5% larger than wool, the coarsest traditional animal fiber. This high linear density, which leads to a low aspect ratio, could possibly pose a problem during the processing stages. However, to overcome this hurdle, the dog fibers could be processed as a short staple yarn. This goes along with the linear density of the fibers. Therefore, again, the preferred manufacturing process for dog fibers would most likely be short staple.

The average modulus of dog hair was 15.3 g/denier. The modulus values for the dog fibers were considerably lower than the modulus values of the traditional animal fibers. However, this factor is situational because in some circumstances a high modulus is favored, whereas, in other circumstances, a low modulus value is more than acceptable. Finally, the average percent strain of the dog fibers was 61.1%. The dog fibers tested required 20.3% more stress than that of wool to show deformation, with wool being the traditional animal fiber with the highest percent strain. This factor is important in establishing that dog fibers are more extensible than the traditionally used animal fibers.

Based on the properties discussed, it would be reasonable to consider dog fiber as a possibility for conversion into staple yarns. With strength, percent strain, and modulus, as a basis, dog fibers would perform equally as well as traditionally used animal fibers, and possibly better in certain instances. The following breeds should be considered as candidates for short staple processing: American Eskimo, Poodle, Sheep Dog, Shih Tzu, Schnauzer, Labrador Retriever, Pekingese, and Westie. The dog breeds that would be appropriate for long staple processing are as follows: Bichon Frise, Cocka-Poo, Lhasa Apso, Pomeranian, and Australian Shepherd.

## 6. FUTURE STUDIES

There are a number of possibilities for future studies in this particular research area. For instance, one might want to modify the scouring procedure of the dog hair fiber. Rather than using Kierlon and soda ash in the scouring bath, perhaps using any other mild pH-balanced detergent as the cleaning agent would be beneficial. Another scouring option would be to scour the dog hair fibers after they have been spun into a chiengora yarn to compare the results. One might also try using vinegar to deodorize the yarn and bring it back to the correct pH.

From the data collected, it is very conceivable to consider dog hair fiber as an appropriate fiber to put into short and long staple yarn manufacturing. This process could be experimented with using 100% dog hair to produce a chiengora yarn, as well as blending dog hair with other fibers to have a nice blended yarn with different characteristics. Obviously, other processing possibilities could be explored such as other spinning methods and/ or nonwoven processing. Studies should be done on which method, knitting and/or weaving is the most beneficial, and how all of these processes mentioned affect the properties of the yarns and fabrics produced.

Finally, consumer acceptance studies should definitely be performed to see how people will react to products created from dog hair. Perhaps a product, such as a chiengora sweater, could be presented to an ordinary consumer as garment A with the label reading 100% chiengora, and an identical garment presented to the consumer as garment B with the label reading 100% dog hair. The consumer would be given the choice of which garment appeals the most to he/she, and present an answer with an explanation as to what prompted them to make the choice that they made. If studies show that consumers are able to look past the fact that the garments are made from dog hair, chiengora may prove to be a profitable and useful fiber.

**REFERENCES**


1. Kaswell, E., "The Tensile Properties of Fibers," Textile Fibers, Yarns, and Fabrics, Reinhold Publishing Corporation, New York, NY, 3-30 (1953).

2. Hunter, L., Mohair: A Review of its Properties, Processing and Applications, International Mohair Association, West Yorkshire, England, 1-15, 48-83, 138-141, 235-245 (1993).

3. Humphries, M., Fabric Reference, Prentice-Hall, Inc., Upper Saddle River, New Jersey, 30-45 (1996).

4. Harmsworth, T. and G. Day, Wool & Mohair: Producing Better Natural Fibres, 2nd Edition, Inkata Press, Sydney, Melbourne, 6-17, 95-100, 193-201 (1990).

5. Morton, W. E. and J. W. S. Hearle, Physical Properties of Textile Fibres, Butterworth & Co. Ltd. and The Textile Institute, Manchester & London, 54-55 (1962).

6. Corbman, B. P., Textiles: Fiber to Fabric, 5th Edition, McGraw-Hill, Inc., New York, 134-166 (1975).

7. Hess, K. P., Textile Fibers and Their Uses, J. B. Lippincott Company, Chicago, Illinois, 123-125, 300-313 (1931).

8. Appleyard, H. M., Guide to the Identification of Animal Fibres, 2nd Edition, Wool Industries Research Association, Leeds, UK, 2-27, 40-117 (1978).

9. Watkins, P. and A. Buxton, Luxury Fibers: Rare Materials for Higher Added Value, Economist Intelligence Unit, London; New York, NY, 6-81, 91-95, 177-184 (1992).

10. Franck, R., Silk, Mohair, Cashmere, and Other Luxury Fibres, Woodhead Publishing Limited and The Textile Institute, Cambridge, England, 69, 146 (2001).

11. Meech, S., Cashmere: A Complete Guide from Fibre to Fashion, Sandy Pines Press, Napanee, Ontario, 1-12, 15-19 (1997).

12. www.theage.com.au/news/2001/02/23/FFX0HIC3IJC.html

13. www.freenet.edmonton.ab.ca/weavers/dog.html

14. www.mdnpd.com/pd/default.htm

15. Crolius, K., and A. Montgomery, Knitting With Dog Hair, St. Martin's Griffin, New York, NY, (1994).

16. www.inetdesign.com/wolfdunn/Yarn1.html

17. Statistical Analysis Software, SAS Institute Inc., Box 8000, Cary, NC, 27512.

18. Trotman, E. R., The Dyeing and Chemical Technology of Textile Fibres, 5th edition, London and High Wycombe: Charles Griffin & Co. Ltd, 92-94 (1975).

19. Alexander, P. and R. Hudson, Wool, Its Chemistry and Physics, 2nd edition, Chapman & Hall Ltd., London, England, 108 (1963).

20. Suh, M. and H. Koo, Estimation of Bundle Modulus and Toughness from HVI Tenacity-Elongation Curves, North Carolina State University, Raleigh, NC, 9 (1997).