Fiber Characteristics of U.S. Huacaya Alpacas

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Not for the first time, we had been encouraged to submit a research proposal to the Alpaca Research Foundation (ARF). This organization had previously funded numerous projects, but breeders were now asking specifically for fiber research. By April 1999, we had discussed the many possibilities among ourselves and with interested breeders and finally had a completed proposal ready to submit. On September 9, 1999, we were informed that ARF would support the project. To cut a long story short, we submitted our final report to ARF on February 19, 2003, 39 pages including 15 tables and 8 figures. A "lay persons" summary (one page, one table!) was also submitted at that time. Our remaining commitments were to publish a refereed journal article (to appear in the *Small Ruminant Research Journal)* and to write a so-called "popular article" for publication in *A.M.* So, here is … the rest of the story.

Introduction

This study sought to define the ranges of quality attributes of domestically-produced huacaya alpaca fiber using internationally accepted methods to objectively measure most of the important fiber characteristics. We proposed to accomplish this by first obtaining, then testing alpaca fiber samples from animals of known age, sex, and shearing status drawn at random from the Alpaca Registry, Inc. (ARI) database and belonging to U.S. breeders of ARI-registered huacaya alpacas. Similar studies conducted for the American Sheep Industry Association had provided information that illustrated the superiority of U.S. wools in terms of resistance to compression (a measure of bulk or loftiness) and staple strength and also the financial benefits that can be obtained by objectively characterizing wool fiber properties prior to sale. It is important for breed associations as well as individual breeders to know the specific attributes (and weaknesses, if any) of their product. A national profile of huacaya alpaca fiber properties did not exist for the U.S.A. Further, the objectively-measured fiber curvature, staple strength, position of break, resistance to compression, and color data that we planned to measure represented new and unique information, since we were unaware of any previous study that had methodically characterized a diverse population of alpacas in terms of these properties.

End-use, product quality, and textile performance of alpaca are determined and restricted by the characteristics of the raw fibers that we proposed to measure in this study. Thus, value and price, at a specific point in time, are also closely related to raw fiber properties.

Our objective in this study was to generate a comprehensive profile of the fiber properties of huacaya alpaca currently being produced in the United States by animals representative of those belonging to members of the Alpaca Registry, Inc. Our hypothesis was that promotion, marketing, selection, and breeding of U.S. huacaya alpacas can all be improved through a comprehensive knowledge of what is currently being produced.

Materials and Methods

After consultation with ARI, a sampling schedule was designed to produce a set of samples that was representative of the regional populations of alpacas. The six geographical regions from which samples were requested were: Central (C) comprising Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas; Great Lakes (GL) comprising Illinois, Indiana, Michigan, Ohio, and Wisconsin; Northeast (NE) comprising Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont; Rocky Mountain (RM) comprising Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming; Southeast (SE) comprising Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia; and West Coast (WC) comprising Alaska, California, Oregon, and Washington.

We requested the samples be shorn from an area 6 inches x 3 inches at skin level on the mid-side of the animal, ideally just before annual shearing. After sealing in a moisture-proof freezer bag, the samples were mailed directly to

Compared to wool of similar fineness, alpaca was shown to be much higher yielding, more heavily medullated (a distinctive feature of alpaca), longer, and considerably stronger.

Fiber Testing Terminology

Normal Distribution

The graph of a normal distribution, the normal curve, is a bell-shaped curve. Many biological phenomena, including animal fiber diameter distributions for single-coated animals, result in data distributed in a close approximation to normal. Hence, statistics applicable to normally distributed populations (mean, standard deviation, and coefficient of variation) are used to define these fiber diameter distributions. The normal curve is symmetric about a vertical center line. This center line passes through the value (the high point of the bell) that is the mean, median and the mode of the distribution. A normal distribution is completely determined when its mean and standard deviation are known.

Approximately sixty-eight percent of all measurements lie within one standard deviation of the mean and approximately 95.0 percent of all measurements lie within two standard deviations of the mean. More than 99.5 percent of all measurements will lie within three standard deviations of the mean.

Fiber Diameter Measurement and Distribution

Fiber diameter is measured in microns. One micron is equal to 1/1,000,000th of a meter or 1/25,400th of one inch. Mean Fiber Diameter (MFD) is in common use internationally. MFD, Standard Deviation (SD), and Coefficient of Variation (CV) all relate to the (approximate) normal distribution of the animal fiber diameters. SD characterizes dispersion of individual measurements around the mean. In a normal population, 66% of the individual values lie within one SD of the mean, 95% within two SD's, and 99% within 2.6 SD's. Since SD tends to increase with increasing MFD, some people prefer to use CV (=SD*100/MFD) as a method of comparing variability about different-sized means.

Comfort Factor

Comfort factor is the percentage of fibers over 30 microns subtracted from 100 percent. Ten percent of fibers over 30 microns corresponds to a comfort factor of 90 percent.

Curvature

Fiber curvature is related to crimp. Average Fiber Curvature (AFC) is determined by the measurement of two millimeter (2mm) snippets in degrees per millimeter (deg/mm). The greater the number of degrees per millimeter, the finer the crimp. For wool, low curvature is described as less than 50 deg/mm, medium curvature as the range of 60-90 deg/mm, and high curvature as greater than100 deg/mm. Typical values might be illustrated by a 30 micron Crossbred wool fleece with typically low curvature and broader crimp with a frequency of approximately two crimps/cm. In contrast, a 21 micron Merino fleece typically has a medium curvature and a medium crimp with a frequency of approximately four (4) crimps/cm. A 16 micron Superfine Merino fleece typically has a high curvature and a fine crimp with a frequency of approximately seven (7) crimps/cm.

Definition of Medullation

A medullated fiber is an animal fiber that in its original state includes a medulla. A medulla in mammalian hair fibers is the more or less continuous cellular marrow inside the cortical layer in most medium and coarse alpaca fibers. By definition (ASTM), a kemp fiber is a medullated fiber in which the diameter of the medulla is 60% or more of the diameter of the fiber.

Medullation Measurement

Medullation measurement can be performed using either a projection microscope or the OFDA 100. Using IWTO nomenclature, a kemp fiber is classified as an "objectionable fiber" when measured on the OFDA 100. The OFDA100 measures opacity and therefore only white or light colored fibers can be measured. A reasonable assumption is that colored fibers have similar levels of medullated fibers as their white and pastel counterparts.

Spinning Fineness

This number (expressed in microns) provides an estimate of the performance of the sample when it is spun into yarn by combining the measured mean fiber diameter (MFD) and the measured coefficient of variation (CV). The original theory comes from Martindale, but the formula used comes from Butler and Dolling and normalizes the equation so that the spinning fineness is the same as the MFD when the CV is 24%.

Length & Strength

Length is measured in millimeters (mm) and the reported measurements readjusted to an annual growth period. Strength is measured in Newtons/kilotex (N/ktex) and is the force (measured in Newtons) required to break a staple of a given thickness (measured in kilotex). On the earth's surface, one kilogram exerts a force of 9.8 Newtons (1kg x acceleration due to gravity measured in meters/second^2). Kilotex indicates thickness in terms of mass per unit length expressed as kg/km.

Intrinsically, alpaca fibers appear to be very strong, an average of 50 N/ktex or better is not unusual. From a processing point of view, a mean staple strength greater than 30 N/ktex is considered adequate for processing wool on today's high-speed equipment.

Resistance to Compression

The resistance to compression (RTC) of alpaca fibers is measured in kilopascals (Kpa). A pascal (Pa) is a unit of pressure equivalent to the force of one Newton per square meter. In the commercial sector, RTC values >11 kPa are considered high, 8 to 11 kPa medium, and <8 kPa is low. The intrinsic resistance to compression of alpaca is low because of the relatively low levels of crimp. Thus, alpaca is not suited to end-uses that require high resistance to compression (or high bulk).

Position of Break

Truly sound fibers break in the middle section of the staple. Intrinsically, alpaca fibers appear to be very strong, in the 50 N/ktex range. A mean staple strength greater than 30 N/ktex is considered adequate for processing wool on today's high-speed equipment.

Clean Yield

Yield is based on bone-dry, extractives-free wool (alpaca) fiber or wool (alpaca) base (WB). Many different "commercial" yields are used in the international marketing of wool fibers. These are values calculated to predict the amount of clean fiber obtained after commercial scouring and/or after combing. Allowances are typically made for grease, ash, vegetable matter, and moisture. Various percentages of moisture are added in these calculations of commercial yield, which in some cases (very clean wool or some alpaca yields) may result in the clean yield exceeding 100%.

Yocom-McColl Testing Laboratories. The following information was requested with each sample: breeder name; farm/ranch name, address, and contact information; animal name; ARI registration number; sex; date of birth or age; body weight; color (from ARI chart); sampling date; and, date last shorn. In this manner, 606 huacaya alpaca samples (representing approximately 1.4% of animals registered in the U.S. [2/1/2003]) were obtained from 44 U.S. breeders (representing approximately 1% of U.S. registered breeders). The following objective measurements were then conducted on each sample using international and national standard methods.

1. Relaxed mean staple length, (MSL, standard deviation [SD], and coefficient of variation [CV]) was determined using 10 staples and the Agritest Staple Length Meter.
2. Mean staple strength (MSS, SD, and CV) and position of break (POB) was determined using 10 staples and an Agritest Staple Breaker Model 2.
3. Lab scoured yield was determined using 2 X 25g subsamples, when this much sample was submitted.
4. Resistance to compression was determined on duplicate scoured, carded, and conditioned subsamples using an Agritest Resistance to Compression Instrument.
5. Scoured samples were minicored and 2 mm snippets were evaluated for average fiber diameter (AFD, SD, and CV), prickle factor (PF), comfort factor (CF), medullation (medullated [MED] and objectionable [OBJ] fibers), and average fiber curvature (AFC and SD) using an Optical Fibre Diameter Analyser 100.
6. A scoured and carded (i.e., homogenized and cleaned) subsample was measured for color using a Spectrogard Color Control System. For each of the three major color groups (in this part of the study: grey, brown, and black), one sample was chosen as the "reference" color and all other samples within the group were compared to it. The difference in color between the standard and any given sample was expressed in terms of ΔE in CIELAB color difference units. For white samples, Yellowness Indexes (YIE) and brightness were measured.

Discussion of the statistical model that was used to analyze the data generated in this study is beyond the scope of this article. Similarly, detailed discussion of all the significant and non-significant interactions that were observed will not be discussed here. Rather, we plan to restrict discussion to the means and distributions of the characteristics measured, correlations among selected measured traits, the effects of sex, age, location, and color on the measured fiber properties, and finally, the overall significance of our study.

Results

Since breeders from some regions were unable (or unwilling) to submit the predetermined number or type of samples (e.g., SE and WC), extra samples were accepted from other regions (e.g., C and RM). In all, 81 samples were tested from the Central region, 140 from the Great Lakes, 94 from the Northeast, 103 from the Rocky Mountains, 18 from the Southeast, and 167 from the West Coast regions. More female (338) than male (209 intact males, plus 56 from geldings) samples were received for testing. Fewer samples were received in the female and male yearling age categories than had been requested. In contrast, many more samples were received from mature females than had been requested. The distribution of animal ages are summarized in ***Figure 1*** (the "0" column indicates animals of unknown age).

In all, 606 samples were received and tested. When requesting samples, we did not attempt to establish quotas for different colors. Natural white proved

Key to Abbreviations Used in Tables

Age, yr	Age, years
BW, lb	Body weight, pounds
AFD, µm	Average fiber diameter, microns
AC, deg/mm	Average curvature, degrees/millimeter
LSY, %	Lab scoured yield, %
MSL, in	Mean staple length, inches
MSS, N/ktex	Mean staple strength, Newtons/kilotex
N	Number of samples tested
RTC, kPa	Resistance to compression, kilopascals
MED, %	Medullated fibers (white and light fawn only), %
OBJ, %	Objectionable fibers (white and light fawn only), %

Table 1. Summary data for properties measured on U.S. huacaya alpaca

Property	N	Mean	SD	CV, %	Min	Max
Age, yr	586	4.1	2.8	68.0	1	17
BW, lb	498	143.7	27.6	19.2	50.0	229.9
AFD, µm	606	27.9	5.3	19.2	15.1	49.3
AC, deg/mm	606	33.2	7.0	21.1	15.4	52.5
LSY, %	605	89.8	4.5	5.0	58.3	95.0
MSL, in	604	4.6	1.6	34.3	2.1	10.9
MSS, N/ktex	605	50.4	21.3	42.4	4.9	137.8
RTC, kPa	595	5.4	0.9	15.7	2.0	7.8
MED, %	277	17.6	11.0	62.2	0.6	61.7
OBJ, %	277	3.8	3.7	97.0	0.1	22.0

Figure 1. Distribution of animal age.

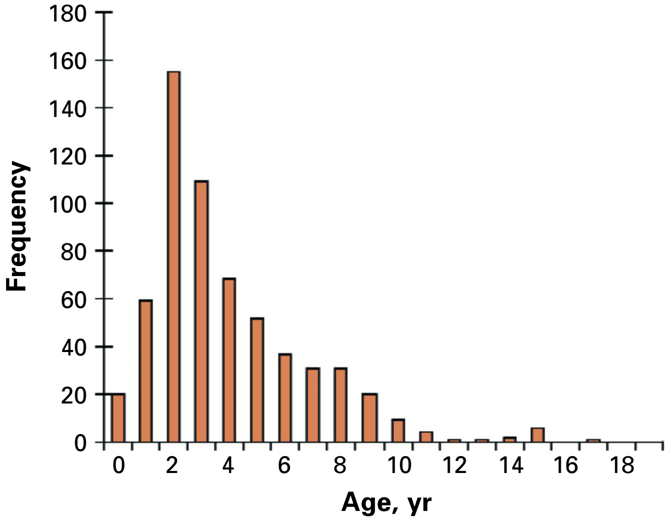


Figure 2. Distribution of body weights

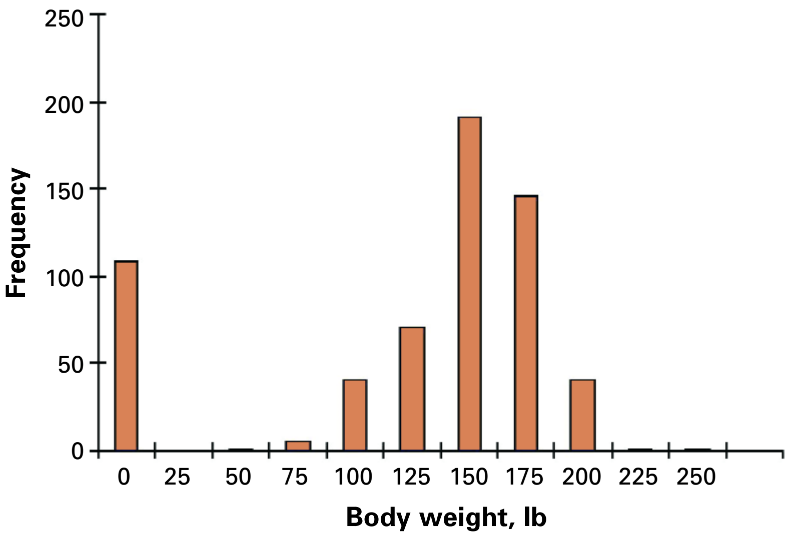
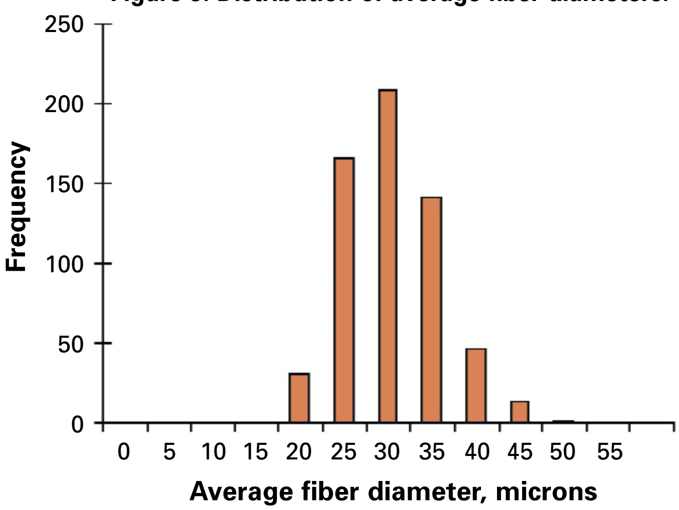


Figure 3. Distribution of average fiber diameters.



to be the largest category (193 samples) followed by natural fawn (106), natural brown (99), natural light fawn (85), natural black (57), natural silver grey (36), and natural rose grey (30).

Table 1 summarizes some of the data submitted, measured, or calculated in the study in terms of number of measurements (N), mean values, standard deviations, coefficients of variation, and minimum and maximum values. To limit the length of this report, we have not included the measures of variability (i.e., SD and CV) associated with each reported mean. In all, 26 characteristics plus the color measurements were recorded for each sample. Only the 10 most important are reported here.

Breeders failed to report age on 20 animals and body weight was not reported for 108 samples. The distribution of body weights for the remaining animals (498) is presented in ***Figure 2*** (the "0" column indicates animals with body weights not reported). Probably the biggest problem in the data collection was failure to report growth period (334 missing values) that would have allowed us to more accurately adjust staple lengths and strengths to 12 months of growth. A few samples were too small for accurate measurement of lab scoured yield, resistance to compression, and color.

The ranges in animal age ***(Figure 1)*** and body weight ***(Figure 2)*** were 1 to 17 years and 50 to 230 pounds, respectively. For the purpose of analysis, age in years was assigned to three categories only: 1 (yearling), 2, and >2 (mature).

Fiber diameter

Differences in AFD and distribution exist among alpacas of the same age and sex, this being attributable to environmental (e.g., nutrition) as well as genetic differences among animals. For most fiber-bearing animals, AFD tends to increase with age. From the perspectives of quality, spinnability, value, and end-use, AFD is the most important characteristic that we measured. The AFD influences many aspects of processing. In general, as AFD decreases, fiber breakage in carding increases, but limiting yarn sizes decrease. A change of 1ìm in AFD outweighs a change in staple length of 10 mm so far as spinning performance (of wool) is concerned.

For both worsted and woolen spinning, AFD and CV of fiber diameter are by far the most important fiber properties influencing spinning performance, yarn, and fabric properties. Yarn hairiness, thickness, short-term irregularity, abrasion resistance, and yarn stiffness all increase with increasing AFD. As AFD increases, pilling resistance improves but tear and bursting strength decrease and fabric handle becomes harsher. For all these reasons, and some others, premiums are invariably paid for finer animal fibers whether it is alpaca, wool, mohair, or cashmere. The range in AFD (15.1 to 49.3 microns, ***Table 1*** and ***Figure 3)*** observed in this study was somewhat larger than expected. ***Table 2*** indicates that AFD is positively correlated with age, body weight, clean yield, and staple strength and negatively correlated with average curvature and staple length.

Fiber curvature

Average fiber curvature is related to crimp frequency (fiber curvature increases as crimp frequency increases) and crimp is directly related to resistance to compression, a good indicator of yarn and fabric bulk or loftiness. The average level of fiber curvature in alpaca is quite low (compared to fine wool or cashmere, for example) and the range in values ***(Figure 4)*** is relatively narrow. ***Table 2*** shows that average fiber curvature is negatively correlated with age, body weight, fiber diameter, clean yield, and staple strength and positively correlated with staple length and resistance to compression.

Clean yield

Raw alpaca contains moisture, and small quantities of grease, sweat, and dirt, in addition to some vegetable material. The buyer is concerned with how much clean alpaca he is buying. A measurement of clean yield allows him to calculate that quantity. A small amount of grease in the fleece is absolutely necessary in order to provide protection against the elements. However, it is important not to select for excessive grease since, all things being equal, a buyer will pay less (even on a clean basis) for excessively greasy fiber. Lab scoured yields of the side samples tested in this study were consistently very high with the majority of samples yielding over 90% ***(Figure 5).***

Table 2. Correlation coefficients between selected animal and fiber traits

	BW	AFD	AC	LSY	MSL	MSS	RTC
Age, yr	0.37**	0.42**	-0.29**	0.01	-0.39**	0.26**	-0.01
BW, lb		0.53**	-0.37**	0.19**	-0.39**	0.44**	0.21**
AFD, µm			-0.85**	0.24**	-0.28**	0.39**	0.06
AC, deg/mm				-0.24**	0.11**	-0.26**	0.10*
LSY, %					0.02	0.09*	-0.00
MSL, in						-0.55**	-0.10*
MSS, N/ktex							0.08

*Significant correlation, P < 0.05
**Highly significant correlation, P < 0.01

Table 3. Tristimulus values, brightness, and yellowness indices for white alpaca samples (N = 241)

Item		Mean	SD	CV	Minimum	Maximum
X	(measure of "redness")	60.71	5.63	9.27	36.15	70.35
Y	(measure of "greenness" and "brightness")	62.53	6.10	9.75	35.61	73.05
Z	(measure of "blueness")	58.90	7.04	11.95	28.84	71.05
YIE	(measure of "yellowness")	19.15	3.02	15.76	12.74	34.62
(Y-Z)	(measure of "yellowness")	3.63	1.68	46.21	-0.79	12.21

Table 4. CIE Tristimulus values and color differences (∆E) for colored alpaca

Item		Mean	SD	CV	Minimum	Maximum
Grey (N = 50)						
L*	(measure of "greenness" and brightness)	15.96	16.21	101.54	-23.87	56.54
a*	(related to (X-Y))	1.26	2.70	214.76	-1.21	9.69
b*	(related to (Y-Z))	3.72	3.86	103.89	-0.36	20.88
∆E	(color difference)	20.12	12.14	60.33	0.44	57.47
Brown (N = 237)						
L*	(measure of "greenness" and brightness)	-12.12	24.07	-198.53	-71.70	64.52
a*	(related to (X-Y))	4.72	6.28	133.05	-7.66	27.50
b*	(related to (Y-Z))	3.78	10.50	277.58	-17.65	35.30
∆E	(color difference)	26.71	14.30	53.52	1.20	72.84
Black (N = 74)						
L*	(measure of "greenness" and brightness)	-4.49	14.14	-315.28	-30.89	42.19
a*	(related to (X-Y))	1.09	2.59	237.85	-2.18	11.86
b*	(related to (Y-Z))	1.30	2.48	190.49	-1.56	11.96
∆E	(color difference)	11.72	9.84	83.94	0.30	42.26

Figure 4. Distribution of average fiber curvatures.

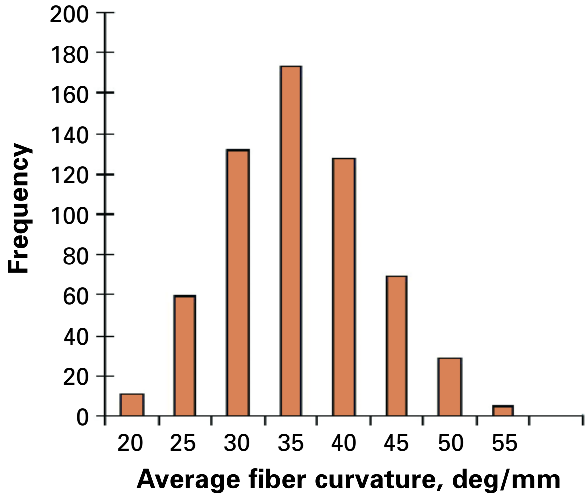


Figure 5. Distribution of lab scoured yields.

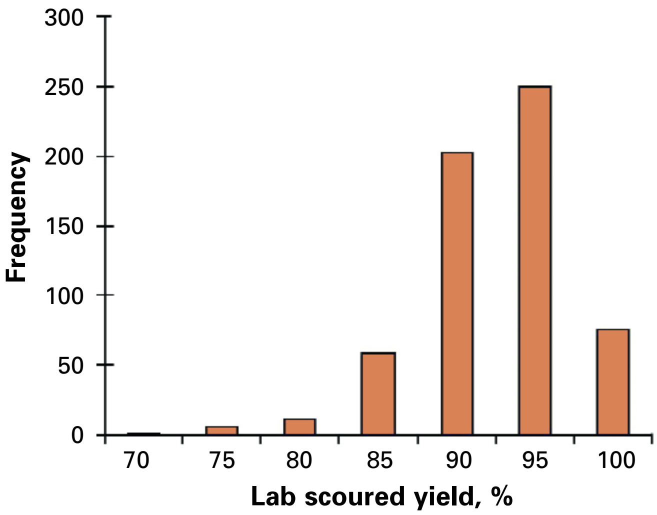
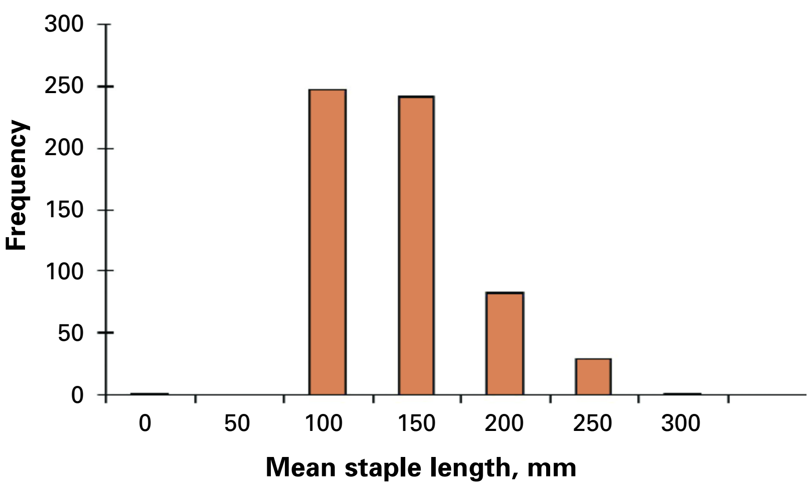


Figure 6. Distribution of mean staple lengths.



A small word of caution here may be warranted. The LSY does not include a correction for vegetable matter content so these yields are slightly inflated. However, for most of the samples, vegetable matter was only present in very small quantities.

Staple length

Staple length and mean fiber length after carding and in top are likely to be highly correlated for "sound" alpaca (MSS > 30 N/ktex). Mean fiber length has a great influence on spinning performance, yarn strength, and uniformity. However, mean fiber length after carding is also influenced, to varying degrees, by crimp, staple strength, position of break, AFD, and the degree of fiber entanglement after scouring. All things being equal, longer fibers produce stronger, more uniform, leaner yarns that have greater resistance to abrasion. Once in fabric, the effects of fiber length diminish compared to effects during the spinning stage. As might be expected, mean staple lengths (actual and adjusted) were generally very adequate (average = 4.6 in) with high within-sample uniformity. The vast majority of samples measured 100 mm or longer (>3.9 in, ***Figure 6***). Again, a word of caution is necessary. The samples tested were from the mid-side and did not include double cuts or any part of the fleece that is normally shorter than that grown on the mid-side.

Staple strength

From a processing point of view, a mean staple strength greater than 30 Newtons per kilotex (N/ktex) has been shown to be adequate for satisfactory processing of wool on today's high-speed equipment. Only about 10% of the alpaca samples measured tested below this benchmark ***(Figure 7)***. Most samples would be considered exceptionally strong. However, within-sample variability tended to be quite high (38.7%) compared to within-sample variability of other traits. Intrinsically, alpaca fibers are very strong.

Resistance to compression

The resistance to compression of alpaca is low ***(Figure 8).*** In the commercial sector, RTC values > 11 kilopascals (kPa) are considered high, 8 to 11 kPa medium, and <8 kPa low. Thus alpaca is not suited to end-uses that require high resistance to compression (or high bulk). To produce alpaca having higher RTC, it would be necessary to select for more crimp.

Medullation

Most alpaca samples were medullated, to varying degrees. Degree of medullation has a great influence on appearance and dyeability. White and light colored fibers having a medulla diameter greater than 60% of the width of the fiber are chalky in appearance and also appear not to accept dyestuff. These are referred to as "objectionable." Lower levels of medullation do not affect appearance, though they affect other fiber properties (e.g., strength). In this study, medullation was estimated from a measure of opacity. Consequently, only natural white and natural light fawn samples were reported. Compared to apparel wool and mohair, the levels of medullated fiber ***(Table 1)*** are generally high and extremely variable. Of course, this is normal and expected for alpaca fiber. However, the minimums for medullated and objectionable (0.6 and 0.1%) are extremely low and suggest that progress might be possible if selection to reduce medullated fiber was attempted.

Color measurement

Numerous subjectively-assessed colors are recognized by the alpaca trade. Objective measurements of color (using a colorimeter) in terms of X, Y, Z, L*, a*, and b* CIE tristimulus values will (potentially) permit fleeces to be accurately described in terms of this trait and also permit ranges to be established for specific color descriptions. Color measurement of scoured "white" wool is now an important component of wool marketing in New Zealand and Australia. Six hundred and two samples were measured using a colorimeter. Of these, 241 were subjectively assessed to be white, and 361 colored. The number of samples designated white for this part of the study was greater than the earlier number assessed as "Natural White" (193) because the assessments were made by different people. No doubt, some Natural Light Fawn samples were included in the white category for color measurement.

Table 3 summarizes the tristimulus values, brightness, and yellowness indices for the 241 white samples. In the CIE system of color measurement, X is a measure of redness, Y is a measure of greenness (also brightness), and Z is a measure of blueness. It has been demonstrated that for white samples, (Y-Z) is a good indicator of yellowness. The typical range in Y for white samples is 70 (very bright) to 40 (very dull). Thus, in this set of samples we have the complete range of brightness values. A range of values of (Y-Z) for scoured and carded U.S. white wool has been reported to be 3 to 10. By contrast, scoured New Zealand and Australian wools are reported to fall in the range 0 to 4. The average (Y-Z) for all white alpaca samples is 3.63, demonstrating that on average they are as white as some of the whitest wool in the world. ***Figure 9*** shows that 33.7% have values >4. YIE values for scoured and carded wools range from 20 to 28, so again the reported mean value for these alpaca samples of 19.15 indicates they appear exceptionally white.

The main conclusion to be drawn from ***Table 3*** and ***Figure 9*** is that wide ranges in yellowness and brightness exist for nominally white alpaca samples. Instrumentation could be very

Table 5. Main effects of sex

	Female	(N)	Male	(N)	Geldings	(N)
BW, lb	143.3	(287)	139.9	(160)	158.5	(50)
AFD, µm	27.7[b]	(338)	27.0[b]	(209)	32.3[a]	(56)
AC, deg/mm	33.5[a]	(338)	33.7[a]	(209)	28.6[b]	(56)
LSY, %	89.5	(337)	90.1	(209)	90.3	(56)
MSL, in	4.3	(337)	5.1	(209)	4.3	(56)
MSS, N/ktex	49.6	(337)	49.9	(209)	56.7	(56)
RTC, kPa	5.42	(336)	5.39	(204)	5.56	(52)
MED, %*	17.7	(141)	17.6	(115)	18.1	(19)
OBJ, %*	3.8	(141)	3.7	(115)	4.6	(19)

*NW and NLF only.

[a,b] Means in a row having different superscripts are different ($P < 0.05$).

Table 6. Main effects of age

	Yearling	(N)	2 years old	(N)	Older than 2 years	(N)
BW, lb	105.8[c]	(46)	130.6[b]	(134)	154.8[a]	(314)
AFD, µm	23.2[c]	(59)	24.9[b]	(155)	29.8[a]	(372)
AC, deg/mm	36.2[a]	(59)	35.8[a]	(155)	31.6[b]	(372)
LSY, %	88.5	(59)	89.5	(155)	90.1	(371)
MSL, in	5.3[a]	(59)	5.6[a]	(155)	4.0[b]	(371)
MSS, N/ktex	28.7[c]	(59)	41.9[b]	(155)	56.9[a]	(371)
RTC, kPa	5.32	(59)	5.41	(154)	5.44	(363)
MED, %*	11.6[b]	(26)	13.7[b]	(79)	20.2[a]	(163)
OBJ, %*	1.9[c]		2.8b[c]		4.4a[b]	

*NW and NLF only.

[a,b,c] Means in a row having different superscripts are different ($P < 0.05$).

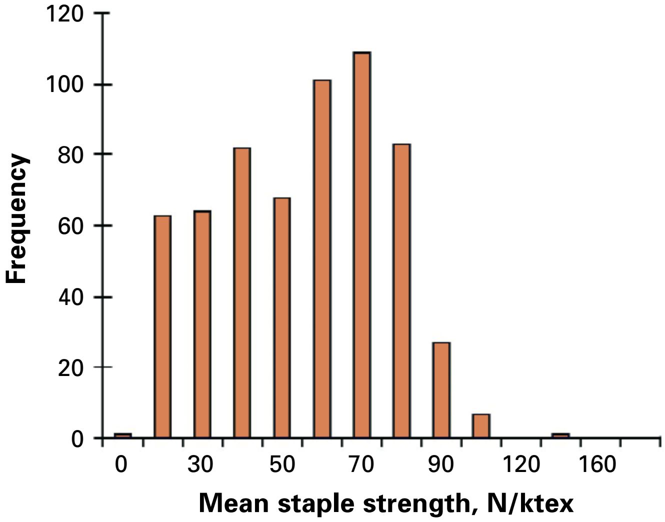


Figure 7. Distribution of mean staple strengths.

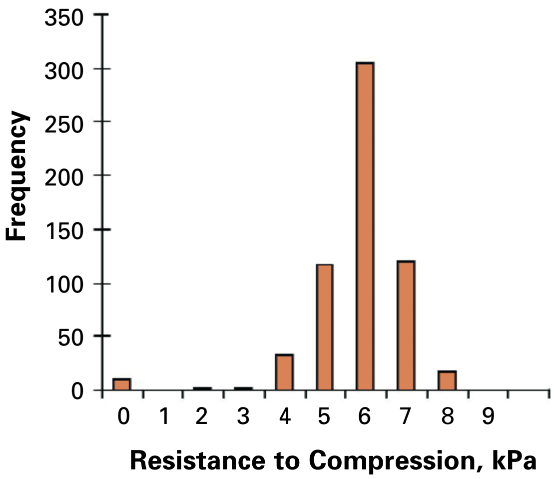


Figure 8. Distribution of resistance to compression.

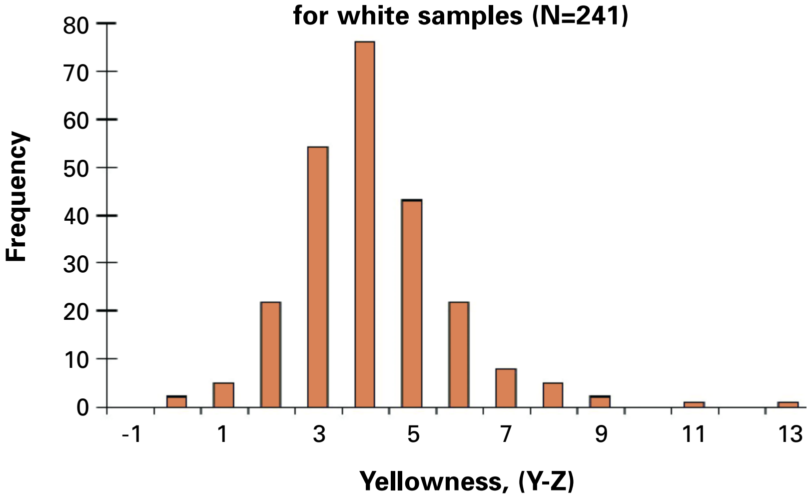


Figure 9. Distribution of yellowness (Y-Z) for white samples (N=241)

useful for establishing white lines of alpaca fiber based on measures of brightness and yellowness.

Table 4 summarizes the CIE tristimulus data and color differences for nominally grey, brown, and black samples. In this method of color difference measurement, L* is the measure of brightness and greenness, a* is related to (X-Y), and b* is related to (Y-Z). ΔE CIELAB is derived from L*, a*, and b* and is the color difference in CIELAB units. Thus, we observe that the average color difference for grey and brown samples is approximately twice the size of that for black. Alternatively stated; the variability in color for the black samples is considerably less than that observed for the grey and brown samples. Nevertheless, there is still a relatively wide range of ΔE values (0.30-42.26), even in the blacks.

Again, the main conclusion from the color measurements summarized in ***Table 4*** is that a great deal of variability exists in these three major color groups. Instrument measurements of individual fleeces could become a very effective tool for establishing uniform color lines of alpaca if such were ever deemed desirable.

Effects of sex, age, color, and region

Due to the presence of several significant interactions in this data set, caution must be used when interpreting the information presented in ***Tables 5, 6, 7, and 8.*** A case in point. ***Table 5*** indicates that males have lower body weights than females (139.9 versus 143.3 lb). Our experience has taught us that for animals of similar age and genetics being maintained in a common environment, the reverse is normally true. But in this data set, the proportion of older females was significantly higher than that of males. Hence, for a more meaningful comparison, it would be necessary to construct a table showing body weights within age group. It is not our intention here to produce a report of such great length and detail that each mean is presented for every level of sex, age, color, and/or region, although the data are available to do this. Because of the importance of average fiber diameter, some extra consideration will be given to this trait later in the report.

Returning to ***Table 5,*** sex appears not to have an effect on most of the measured traits. Gelded males have coarser fiber than intact males and females but again, it must be pointed out that most of the geldings measured were three years of age or older.

Most of the trends observed in ***Table 6*** appear to be intuitively correct. This table quantifies the magnitudes of the effects of age. As alpacas age, their body weights, fiber diameters, staple strengths, and percentage of medullated fibers all increase. However, fiber curvature, and staple length decrease. Lab scoured yield and resistance to compression appear to be independent of age, the latter observation being somewhat surprising.

Table 7 summarizes differences attributable to color. One indication from this table is that black samples were on average coarser than white samples with most of the other colors being intermediate. Again caution is required. Before this comparison can be properly made, it is necessary to take into account the different ages and sexes of the animals involved, as we do in a later analysis. Small differences occur in several of the other traits, but again, the same caution is provided.

Table 8 summarizes the differences in means attributable to region which reflect (to unknown degrees) the different environmental conditions encountered as well as the different genetics that are present. The effects of region are also confounded by age and sex. Generally, animals from the WC region tended to be lighter in weight and produce finer, longer, but weaker fibers with higher fiber curvature. Inexplicably, the higher fiber curvature did not appear to produce fibers having higher resistance to compression.

Table 9 shows the effects of sex and age on fiber diameter. For a particular age group, AFD does not differ between females and intact males. In fact, fiber samples from yearling and two-year-olds were not significantly different. Mature geldings were shown to be coarser than mature females and intact males (by about 3 microns).

Further discussion of correlations

Table 2 lists the Pearson correlation coefficients between selected animal and fiber traits. A knowledge of correlations between traits is necessary for a better understanding of the likely

Table 7. Main effects of color

	Natural White		Natural Light Fawn		Natural Fawn		Natural Brown		Natural Rose Gray		Natural Silver Gray		Natural Black	
BW, lb	145.8^{abc}	(155)	133.6^{d}	(66)	137.9^{cd}	(93)	148.8^{ab}	(84)	140.3^{bc}	(23)	151.7^{a}	(32)	149.7^{a}	(45)
AFD, µm	26.4^{d}	(193)	26.0^{d}	(85)	27.0^{cd}	(106)	30.0^{b}	(99)	28.4^{c}	(30)	30.5^{ab}	(36)	31.6^{a}	(57)
AC, deg/mm	35.7^{a}	(193)	35.9^{a}	(85)	33.8^{ab}	(106)	29.9^{c}	(99)	32.5^{b}	(30)	29.9^{c}	(36)	27.1^{d}	(57)
LSY, %	89.5	(192)	89.6	(85)	90.6	(106)	90.0	(99)	89.4	(30)	89.2	(36)	90.1	(57)
MSL, in	4.7^{a}	(192)	4.8^{a}	(85)	4.7^{a}	(106)	4.5^{ab}	(99)	4.6^{a}	(30)	4.2^{bc}	(36)	4.0^{c}	(57)
MSS, N/ktex	50.2^{ab}	(192)	51.1^{ab}	(85)	49.9^{ab}	(106)	50.7^{ab}	(99)	44.9^{b}	(30)	55.3^{a}	(36)	50.1^{ab}	(57)
RTC, kPa	5.64^{a}	(188)	5.51^{ab}	(84)	5.43^{ab}	(102)	5.22^{bc}	(99)	5.46^{ab}	(29)	5.29^{b}	(36)	5.0^{c}	(57)
MED, %*	17.9	(192)	17.2	(85)	–		–		–		–		–	
OBJ, %*	3.9	(192)	3.6	(85)	–		–		–		–		–	

*Natural White and Natural Light Fawn only.

a,b,c Means in a row having different superscripts are different ($P < 0.05$).

Table 8. Main effects of region

	Central		Great Lakes		Northeast		Rocky Mountain		Southeast		West Coast	
BW, lb	142.1^{bc}	(75)	156.0^{a}	(126)	152.0^{ab}	(47)	141.9^{bc}	(79)	139.5^{c}	(10)	133.5^{c}	(161)
AFD, µm	29.5^{a}	(82)	29.2^{a}	(141)	29.9^{a}	(94)	26.5^{b}	(103)	30.3^{a}	(18)	25.4^{b}	(168)
AC, deg/mm	31.1^{b}	(82)	31.4^{b}	(141)	31.1^{b}	(94)	35.2^{a}	(103)	30.8^{b}	(18)	35.7^{a}	(168)
LSY, %	90.3^{abc}	(82)	89.2^{cd}	(141)	88.1^{d}	(93)	89.8^{bc}	(103)	91.6^{a}	(18)	91.0^{ab}	(168)
MSL, in	5.1^{b}	(82)	3.6^{e}	(141)	4.4^{c}	(93)	4.3^{cd}	(103)	3.8^{de}	(18)	5.7^{a}	(168)
MSS, N/ktex	47.9^{bc}	(82)	58.5^{a}	(141)	54.0^{ab}	(93)	46.1^{c}	(103)	49.6^{bc}	(18)	45.5^{c}	(168)
RTC, kPa	6.18^{a}	(74)	5.47^{bc}	(141)	5.29^{bc}	(92)	5.31^{bc}	(103)	5.60^{b}	(18)	5.17^{c}	(167)
MED, %*	21.6	(52)	17.2	(36)	21.0	(42)	15.8	(51)	20.0	(5)	15.0	(91)
OBJ, %*	5.6^{a}		3.3^{ab}		4.9^{ab}		3.2^{b}		4.8^{ab}		2.7^{b}	

*Natural White and Natural Light Fawn only.

a,b,c Means in a row having different superscripts are different ($P < 0.05$).

Table 9. Least squares means of average fiber diameter by sex and age

Sex	Age, yr	AFD, µm	N
F	1	23.7[c]	31
F	2	26.4[c]	77
F	>2	29.9[b]	224
M	1	24.3[c]	28
M	2	25.8[c]	75
M	>2	30.8[b]	95
G	1	—	0
G	2	24.8[c]	3
G	>2	33.1[a]	52

[a,b,c] Means in a column having different superscripts are different ($P < 0.05$).

results of selective breeding. A correlation coefficient (r) of 1 between two characteristics indicates that one characteristic may be used to perfectly predict the other (a rare occurrence in nature). An r value of 0 indicates there is no relationship between the two characteristics. A P value of < 0.05 indicates this is not a chance occurrence and that a significant relationship exists. Thus AGE is positively and significantly correlated with BW, AFD, and MSS and negatively and significantly correlated with AC and MSL. Correlations between AGE and LSY and AGE and RTC are not significant (P > 0.8). Interpretation: as animals age, BW, AFD and MSS increase, AC and MSL decrease and LSY and RTC are unaffected. These trends seem intuitively correct (with the possible exception of RTC) and are somewhat similar to trends observed for sheep and Angora goats, as are many of the correlations listed in ***Table 2.***

The AFD, LSY, MSS, and RTC are positively correlated with BW, while larger BW are associated with lower AC and MSL. This latter negative correlation would not be expected for wool. The highest reported r value is a negative correlation between AFD and AC, i.e., as fibers become coarser, curvature decreases, i.e., crimp frequency declines.

The AFD is also negatively correlated with MSL. This observation does not match those made among different breeds of sheep for which we notice the coarser breeds generally grow longer wool. However, it does match our observations within the breed of fine-wool Rambouillet sheep. This negative correlation is also different than that reported by other researchers for adult alpacas being farmed in New Zealand. However, most of the correlations between the remaining fleece characteristics are very similar in magnitude and significance to those reported in the present study. Coarser alpaca tends to yield higher and be stronger.

In the populations tested in New Zealand and the U.S., AFD and RTC were not significantly correlated. This was not entirely predictable. In wool, for example, finer fibers tend to have more crimp that results in a positive, significant correlation with RTC. However, truly fine wools also exist, having very bold crimp and predictably, these wools have relatively low RTC. The AC turns out to be a slightly better predictor of RTC, but is negatively correlated with LSY and MSS. The remaining correlations between LSY and MSL, MSS, and RTC are all very low, although the relationship with MSS is just significant (P = 0.03). MSL was shown to be negatively and quite highly correlated with MSS and lowly correlated with RTC. Finally, MSS and RTC had a very small, positive correlation.

Summary

A study was conducted to establish a comprehensive profile of U.S. huacaya alpaca fiber characteristics that will be useful for educational, promotional, policy, selection, and breeding purposes. Specifically, the ranges, means, and distributions of all important fiber characteristics and body weights of U.S. alpacas were measured and calculated using internationally accepted objective test methods. Animals in specified age ranges and of known sex representing six geographical regions in the U.S. were weighed and sampled in approximate proportion to their population density in the respective regions. Fiber samples were shorn from the mid-side of six hundred and six alpacas representing female, male, and castrated male registered animals in the three age categories: one- and two-year-old and adult, and then sent to the commercial testing laboratory.

Additionally, each sample was measured for average fiber diameter (and SD and CV), comfort factor, average fiber curvature (and SD and CV), medullation (white and light fawn samples only), lab scoured yield, average staple length (and SD and CV), staple strength, position of break, resistance to compression, color differences (colored samples), and brightness and yellowness (white samples). Compared to wool of similar fineness, alpaca was shown to be much higher yielding, more heavily medullated (a distinctive feature of alpaca), longer, and considerably stronger. Resistance to compression was invariably lower for alpaca compared to wool of comparable dimensions, due primarily to the generally lower levels of crimp in the alpaca fibers. Less crimp results in leaner, smoother, less bulky yarns and fabrics, an attribute for worsted (but not woolen) constructions. In addition, data were analyzed (results to be presented in a refereed journal article) in terms of sex, age, region, color, and their interactions.

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