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Fiber characteristics of the Huacaya Alpaca

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Abstract

A study was conducted to establish a comprehensive profile of US Huacaya Alpaca fiber characteristics that could be useful for educational, promotional, policy, selection, and breeding purposes. Specifically, the means, distributions, and ranges of 23 fiber characteristics and body weight of a representative sample ($n=585$) of US Alpacas were measured or calculated using internationally accepted objective test methods. Animals in specified age groups and of known sex representing six geographical regions in the USA were weighed and sampled in approximate proportion to their population density in the respective regions. Fiber samples were shorn from the mid-side of the Alpacas, representing female, male, and castrated male registered animals in the three age categories: 1- and 2-year-old and adult Alpacas. Each sample was measured for mean fiber diameter, prickle factor, comfort factor, mean fiber curvature, medullation (white and light fawn samples only), laboratory scoured yield, mean staple length, mean staple strength, position of break, and resistance to compression. In addition, yellowness and brightness were measured on the white samples and color differences were measured on the colored samples using a colorimeter. With one exception (laboratory scoured yield), the measured characteristics exhibited considerable variability. The only difference in fiber characteristics that was attributable to sex was mean staple strength. Males produced stronger fibers than females. In contrast, differences due to age were apparent for all but two of the measured traits, these being coefficient of variation of staple length and resistance to compression. Compared to wool of comparable fineness, the Alpaca was shown to be 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 fiber diameter likely due to the lower levels of crimp in the Alpaca fibers.

Keywords: Alpaca; Huacaya; Objective fiber measurements; Sex; Age; Color

1. Introduction

The Alpaca (*Lama pacos*) is commercially the most important fiber producer of the South American camelid family. Two breeds of Alpaca are recognized,

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the Huacaya and the Suri. This study deals exclusively with the more popular, crimpy-fleeced Huacayas. Alpacas are indigenous to the Andean highlands of South America. Of the approximately 3.5 million in the world, most (∼3.0 million) are located in Peru, with the majority of the remainder in Chile and Bolivia. These numbers in South America have been fairly static due in part to the lower, more productive altitudes (2600–3400 m) being used for sheep and cattle production. The Peruvian Alpacas produce approximately 90% of the world's camelid fiber production (Pumayalla and Leyva, 1988). Until about 20 years ago, Alpacas were considered to be specifically adapted to their native environment. However, successful introductions of the species to Australia, Canada, England, France, New Zealand, and the USA have shown that Alpacas are more versatile than previously recognized.

Production traits have been documented in several studies (e.g., Castellaro et al., 1998) in their native South American environment (latitude 5–20°S, longitude 70–80°W, altitude 2500–5000 m), where the animals are often undernourished for at least part of the production year. Studies conducted in New Zealand (Wuliji et al., 2000) and Australia (McGregor, 2002) have also been reported. More than 49,000 Alpacas were maintained in the USA in December 2003 (Alpaca Registry, 2004). It is of interest to the more than 5600 owners (as well as the scientific community) to establish means and ranges of important quality traits of US Alpaca (produced by animals purchased and maintained primarily for investment purposes), that could be substantially different than the fiber produced in South America (by animals primarily managed for commercial production of fiber and meat). Similar studies conducted for the American Sheep Industry Association (e.g., Blakeman et al., 1991) provided information that illustrated the superiority of US wools in terms of resistance to compression (a measure of bulk or loftiness) and staple strength and also the financial benefits that could be obtained by objectively characterizing the wool fiber properties prior to sale (Lupton et al., 1993). The objective of this study was to generate a comprehensive profile of the fiber properties of the Huacaya Alpaca currently being produced in the USA as such a

Table 1
Key to abbreviations used in text and tables

Age (yr)	Age, years
BW (kg)	Body weight, kg
GP (mo)	Growth period, months
MFD (μm)	Mean fiber diameter, μm
SD (μm)	Standard deviation of fiber diameter, μm
CV (%)	Coefficient of variation of fiber diameter, %
PF (%)	Prickle factor, fibers >30 μm, %
CF (%)	Comfort factor, fibers ≤30 μm, %
AC (°/mm)	Mean curvature, °/mm
CSD (°/mm)	Standard deviation of fiber curvature, °/mm
MED (per 10,000)	Medullated fibers (white and light fawn samples only), per 10,000
OBJ (per 10,000)	Objectionable fibers (white and light fawn samples only), per 10,000
LSY (%)	Lab scoured yield, %
MSL (mm)	Mean staple length, mm
LSD (mm)	Standard deviation of staple length, mm
LCV (%)	Coefficient of variation of staple length, %
ADJ MSL (mm)	Adjusted mean staple length, mm
ADJ LSD (mm)	Adjusted standard deviation of staple length, mm
ADJ LCV (%)	Adjusted coefficient of variation of staple length, %
MSS (N/ktex)	Mean staple strength, N/ktex
SSD (N/ktex)	Standard deviation of staple strength, N/ktex
SCV (%)	Coefficient of variation of staple strength, %
POB, tip (%)	Position of break in top third of staple, %
POB, middle (%)	Position of break in middle third of staple, %
POB, base (%)	Position of break in base third of staple, %
RTC (kPa)	Resistance to compression, kPa

national profile does not exist. Further, the objectively measured fiber curvature, staple strength, position of break, and resistance to compression data represent new and unique information as previous studies have not methodically characterized a diverse population of Alpacas in terms of these properties (Table 1).

2. Materials and methods

2.1. Sample description

Five hundred and eighty-five Huacaya Alpaca fiber samples (representing approximately 1.2% of animals registered in the USA) were obtained from 44 breeders (representing approximately 0.8% of the US registered breeders) with the assistance of the Alpaca Registry Inc. (ARI). The original plan was to obtain 66 or 67 each in the following age and sex categories: 1- and 2-year-old and adult males (age $\geq$ 3 years); 1- and 2-year-old and adult females; 1- and 2-year-old and adult castrated males. However, this plan was modified after consultation with ARI and the sampling schedule outlined in Tables 2–5 was used to produce a set of samples that was more representative of the regional populations of Alpacas while reducing the number of samples to be tested from castrated animals. The six geographical regions from which samples were requested were the Central (C) states comprising Arkansas, Iowa, Kansas, Louisiana, Minnesota, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota, and Texas; the Great Lakes (GL) area comprising Illinois, Indiana, Michigan, Ohio, and Wisconsin; the Northeastern (NE) states comprising Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont; the Rocky Mountain (RM) region comprising Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming; the Southeastern (SE) states comprising Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia; the West Coast (WC) region comprising Alaska, California, Oregon, and Washington. It was requested that the samples be

Table 2
Sex and age distribution of sampled Alpacas

Age (yr)	Number	Total
Female		
1	31	
2	77	332
>2	224	
Male		
1	28	
2	75	198
>2	95	
Castrate		
1	0	
2	3	55
>2	52	

Table 3
Distribution of tested Alpacas by region and sex

Sex	Region					
	C	GL	NE	RM	SE	WC
F	30	108	50	50	9	85
C	16	6	11	11	2	9
M	29	26	25	41	7	70
Total	75	140	86	102	18	164

Key: Region: C, Central; GL, Great lakes; NE, Northeast; RM, Rocky mountain; SE, Southeast; WC, West coast. Sex: F, female; C, castrate; M, male.

Table 4
Distribution of tested Alpacas by region and age

Age (yr)	Region					
	C	GL	NE	RM	SE	WC
1	8	14	8	13	1	15
2	14	21	17	28	2	73
>2	53	105	61	61	15	76
Total	75	140	86	102	18	164

Key: Region: C, Central; GL, Great lakes; NE, Northeast; RM, Rocky mountain; SE, Southeast; WC, West coast.

Table 5
Distribution of tested Alpacas by color

Color	Number
NB	55
NBR	95
NF	103
NLF	80
NRG	29
NSG	35
NW	188

Key: NB, natural black; NBR, natural brown; NF, natural fawn; NLF, natural light fawn; NRG, natural rose grey; NSG, natural silver grey; NW, natural white.

shorn from an area 15 cm × 7.5 cm at skin level on the mid-side of the animal ideally just before the annual shearing. After sealing in a moisture-proof freezer bag, the samples were mailed directly to Yocom-McColl testing laboratories. The following information was provided 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 (ARI description); sampling date; date last shorn.

2.2. Methods of test

The following objective measurements were conducted on each sample using the referenced international or national standard methods. Relaxed mean staple length (MSL) was determined using 10 staples and the Agritest staple length meter (IWTO-30, 1998). Mean staple strength (MSS) and position of break (POB) were determined using 10 staples and an Agritest Staple Breaker Model 2 (IWTO-30, 1998). Laboratory scoured yield (LSY) was determined using 2 × 25 g sub-samples (ASTM D 584, 2003), when this much sample was available. Resistance to compression was determined on duplicate washed, carded, and conditioned sub-samples using an Agritest Resistance to Compression Instrument (Australian Standard 3535, 1988). Washed samples were minicored and 2 mm snippets were evaluated for mean fiber diameter (MFD), prickle factor (PF), comfort factor (CF), medullation (medullated [MED], and objectionable [OBJ] fibers, natural white, and light fawn samples only), and mean fiber curvature (MFC) using an Optical Fibre Diameter Analyser (IWTO-47, 2000; IWTO-57, 1998, and an Australian/New Zealand draft method, 2000 respectively).

A washed and carded (i.e., homogenized and cleaned) sub-sample was measured for color using a Spectrogard Color Control System (Pacific Scientific) using the AATCC evaluation procedure 7 for instrumental assessment of the change in color of a test specimen (2002 AATCC Technical Manual). For each major color group (in this part of the study, nominally grey, brown, and black), one sample was chosen as the "standard" color and all other samples within the group were compared to it. The difference in color between the standard and any given sample is expressed in terms of ΔE in CIELAB color difference units. For white samples, the formula described in ASTM E313-96 (ASTM, 1998) was used to calculate the yellowness index (YIE). In addition, (Y–Z) the difference between green and blue tristimulus values was reported as another indicator of yellowness. Also for white samples, we reported the tristimulus value Y that (in addition to being a measure of greenness) is a measure of total reflectance or brightness.

2.3. Statistical analysis

The general linear model procedure (PROC GLM) of SAS (SAS Institute Inc., Cary, NC) was used to calculate and separate means (Duncan's multiple-range test) and least squares means for the 26 characteristics recorded in this study. Main effects in the model were sex (3), age (3), region (6), and color (7). Originally, the four main effects plus the six 2-way, four 3-way, and one 4-way interaction were all include in the model. Subsequently, interactions that were not significant for any variables were removed (i.e., sex × color, age × color, age × region × color, sex × region × color, sex × age × color, and the 4-way interaction). Four of the remaining five interactions included region. As data from only one production year were available, differences attributable to region could in fact be due to irreproducible environmental (e.g., meteorological) factors and dietary differences. Genetic differences between regions may also be present in this population. Consequently, interactions including region were also removed from the model leaving the main effects and the sex × age interaction. Though the significance of region on Alpaca traits is noted (Table 7), no further discussion of this topic is presented due to the aforementioned potentially confounding factors. The CORR procedure of SAS (2000) was used to calculate correlation coefficients between selected characteristics.

3. Results and discussion

3.1. Sample description and summary statistics

Table 2 sets out the distribution of samples by sex and age. More female (332) than male (198) samples were received for testing. Table 3 illustrates the distribution of the samples tested by geographical region and sex. Most samples were received from the WC region, the least number from the SE region. Table 4 summarizes the animal age data by region. Most samples were from mature (>2-year-old) animals. When requesting samples, no attempt was made to establish quotas for the different colors. The distribution of samples by color is presented in Table 5. Natural white was the largest category with natural rose grey being the smallest. In all, 585 samples were received and tested and these represented 174 of the possible 378 sex × age × region × color permutations.

Table 6 summarizes all the data collected, measured or calculated in the study in terms of number of measurements (*N*), mean values, standard deviations (SD), coefficients of variation (CV), and minimum and maximum values. Body weight was not reported for 92 samples. However, by far the biggest problem in the submission of data was failure to report the growth period (321 missing values). One sample was too small for accurate measurement of LSY and staple strength and 10 were too small for measurement of resistance to compression.

The ranges in animal age and body weight were 1–17 year and 22.7–104.3 kg, respectively. The growth period for the submitted Alpaca samples ranged from 4 to 14 months with the majority being close to 12 months. Further, the similarity in magnitude (a difference of less than 1 mm) between actual mean staple length for all the samples measured (585) and the adjusted MSL for the 264 samples for which growth periods were reported, indicates the majority of the unreported growth periods were close to 12 months.

The ranges in MFD (15.09–49.27 μm), SD, and CV were large and from the point of view of quality, spinnability, value, and end-use, MFD was seen as the most important characteristic measured. The MFD influences many aspects of processing. In general, as the MFD decreases, fiber breakage in carding increases, and limiting yarn size decrease. A change of 1 μm in the MFD outweighs a change in staple length of 10 mm so far as spinning performance of wool is concerned (Hunter, 1980). For both worsted and woolen spinning, MFD 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 MFD. As MFD increases, pilling resistance improves, but tear and bursting strength decreases 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.

High MFD is generally associated with relatively low crimp frequency (and vice versa), which is in turn directly proportional to fiber curvature. The mean level of fiber curvature for these samples was low (compared to fine wool or cashmere), and the range in values (15.4–52.5°/mm) was relatively small. The MFC measurement has been shown to be closely related to crimp propensity in wool (Edmunds and Sumner, 1996) and "style" in cashmere (Lupton et al., 1999). Crimp is related to resistance to compression, an indicator of yarn and fabric bulk and loftiness.

Most Alpaca samples are medullated to varying degrees and this degree of medullation has a great influence on the appearance and dyeability. Compared to apparel wool and mohair, the levels of medullated fiber are high and extremely variable. Of course, this is normal and expected for Alpaca fiber. However, the minimum values for MED and OBJ (0.59 and 0.09%) are extremely low that suggests progress may be possible if selection to reduce medullated fiber is practiced assuming this is ever deemed desirable by breeders or the textile trade.

Raw Alpaca contains moisture, and small quantities of grease, suint, and dirt in addition to some vegetable material. The LSY is measured to estimate the percentage of clean fiber in a sample. A small amount of grease in the fleece is absolutely necessary in order to provide some protection against the elements. However, it is important not to select for excessive grease because, all things being equal, a buyer will pay less (even on a clean basis) for excessively greasy fiber. The LSY of the side samples tested in this study were consistently very high with the majority of samples yielding over 90%. A word of caution here may be warranted. The LSY does not include a deduction for vegetable matter content, so yields reported here are somewhat inflated. Visual appraisal of the samples indicated vegetable matter was either absent or present in very small quantities.

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, MFD, and the degree of fiber entanglement after washing. All things being equal, longer fibers pro-

Table 6
Summary statistics for properties measured on Alpaca samples grown in the USA

Property	*N*	Mean	SD	CV	Min	Max
Age (yr)	585	4.08	2.77	68.02	1	17
BW (kg)	493	65.16	12.54	19.25	22.68	104.33
GP (mo)	264	11.73	1.10	9.39	4	14
MFD (μm)	585	27.85	5.35	19.23	15.09	49.27
SD (μm)	585	6.52	1.59	24.42	3.81	14.34
CV (%)	585	23.48	3.55	15.11	15.06	39.24
PF (%)	585	31.61	25.05	79.23	0.68	96.62
CF (%)	585	68.39	25.05	36.62	3.38	99.32
AC (°/mm)	585	33.16	7.00	21.10	15.39	52.51
CSD (°/mm)	585	31.06	5.79	18.65	15.94	52.56
MED (per 10,000)*	267	1748	1097	62.8	59	6172
OBJ (per 10,000)*	267	371	363	97.8	9	2237
LSY (%)	584	89.77	4.50	5.01	58.27	95.00
MSL (mm)	583	116.28	39.97	34.37	53.80	276.00
LSD (mm)	583	7.74	4.60	59.46	2.06	42.28
LCV (%)	583	6.80	3.41	50.10	1.84	28.09
ADJ MSL (mm)	264	116.46	41.51	35.64	59.10	350.10
ADJ LSD (mm)	264	7.98	5.13	64.22	2.06	42.28
ADJ LCV (%)	264	6.87	3.54	51.52	2.06	28.09
MSS (N/ktex)	584	50.16	21.40	42.66	4.86	137.80
SSD (N/ktex)	584	17.33	8.43	48.65	1.25	52.53
SCV (%)	584	38.62	17.80	46.09	4.42	112.98
POB, tip (%)	584	31.25	29.68	94.98	0.00	100.00
POB, middle (%)	584	51.77	26.42	51.06	0.00	100.00
POB, base (%)	584	16.79	22.29	134.21	0.00	100.00
RTC (kPa)	575	5.42	0.84	15.44	2.89	7.80

Key: see Table 1.
* NW and NLF samples only.

duce 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 for processing (mean = 116 mm) with high within-sample uniformity. Again, a small word of caution: the samples tested were shorn from the mid-side of the animals so did not include double cuts or any part of the fleece that is normally shorter than that grown on the mid-side.

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 (Blakeman et al., 1991). Only about 10% of the samples measured tested below this benchmark. Most samples could be considered exceptionally strong. However, within-sample variability tended to be quite high (38.62%), compared to within-sample variability of fiber diameter and staple length (but not curvature). Truly sound fibers break in the middle section of the staple, this being true for 51.8% of the samples in this study. However, 31.3% broke at the top third of the staple, a possible result of weathering or some other environmental factors. Intrinsically, Alpaca fibers appear to be very strong.

In contrast, the intrinsic resistance to compression of Alpaca is low. In the commercial wool sector, RTC values >11 kPa are considered high, 8–11 kPa medium, and <8 kPa low. Thus, Alpaca is not suited for end-uses that require high resistance to compression (or high bulk). If it were desired to produce Alpaca having higher RTC, it would be necessary to select for more crimp.

3.2. *Significant sex × age interactions*

Table 7 documents the significance values of the four main effects, sex, age, region, and color and the sex × age interaction for each of the recorded variables.

Table 7
Significance (*P*-values) of main effects and sex × age interaction for Alpaca body weight and fiber characteristics

	Sex	Age	Region	Color	Sex × age
BW (kg)	0.0001	0.0001	0.0001	0.4902	0.5448
MFD (μm)	0.0001	0.0001	0.0001	0.0001	0.1351
SD (μm)	0.0001	0.0001	0.0001	0.0001	0.0596
CV (%)	0.4847	0.0164	0.0001	0.2168	0.1484
PF (%)	0.0001	0.0001	0.0001	0.0001	0.3541
CF (%)	0.0001	0.0001	0.0001	0.0001	0.3541
AC (°/mm)	0.0001	0.0001	0.0001	0.0001	0.0469
CSD (°/mm)	0.0001	0.0001	0.0001	0.0001	0.0703
MED (per 10,000)*	0.9179	0.0001	0.0389	0.6717	0.9611
OBJ (per 10,000)*	0.4585	0.0001	0.0014	0.5844	0.8419
LSY (%)	0.3509	0.0187	0.0001	0.1754	0.0162
MSL (mm)	0.0001	0.0001	0.0001	0.8026	0.1192
LSD (mm)	0.2870	0.0001	0.0001	0.2376	0.0076
LCV (%)	0.0420	0.0564	0.0001	0.1966	0.0456
ADJ MSL (mm)	0.0014	0.0034	0.0001	0.3508	0.6516
ADJ LSD (mm)	0.3173	0.0003	0.0001	0.2711	0.0058
ADJ LCV (%)	0.3347	0.0403	0.0001	0.1527	0.0071
MSS (N/ktex)	0.0169	0.0001	0.0001	0.1544	0.0439
SSD (N/ktex)	0.0001	0.0001	0.0023	0.0960	0.2444
SCV (%)	0.1173	0.0002	0.0018	0.0037	0.6772
POB, tip (%)	0.0015	0.0001	0.0001	0.1101	0.5264
POB, middle (%)	0.0191	0.0001	0.0158	0.4588	0.8170
POB, base (%)	0.4991	0.0001	0.0001	0.0630	0.7184
RTC (kPa)	0.2350	0.6965	0.0001	0.0001	0.0798

Key: see Table 1.
* NW and NLF samples only.

Table 8 lists the least squares means for those traits in which the sex × age interaction was significant. For females, mean curvature was not different among ages. However, for males and castrates, curvature decreased with age. In the case of LSY, the general trend was for older animals to have higher yields. In the case of castrates, however, the difference between the two age groups was not significant. In the case of staple length variability (LSD, LCV, ADJ LSD, and ADJ LCV, but only LSD means appear in Table 8), samples from yearling females were more variable in length than those from older animals. In the case of males, samples from 2-year-old were more variable in length than from older animals with yearling variability being intermediate. The small number of samples from 2-year-old castrates was extremely uniform in length, compared to those from older castrates (and all other categories). The MSS of samples from females increased with age. For males, this same trend was apparent but the strengths of samples from yearlings and 2-year-old were not different.

Table 8
Least squares means of Alpaca fiber characteristics for traits in which the sex × age interaction was significant

Trait	Sex	Age		
		1	2	>2
AC	F	34.1	33.7	32.0
	M	35.0^{a}	33.4^{a}	29.8^{b}
	G	–	36.9^{a}	27.8^{b}
LSY	F	87.9^{b}	89.8^{a}	89.8^{a}
	M	89.0^{b}	88.4^{b}	91.1^{a}
	G	–	88.6	90.5
LSD	F	10.7^{a}	8.8^{b}	7.7^{b}
	M	$8.7^{a,b}$	9.6^{a}	7.1^{b}
	G	–	2.9^{b}	8.3^{a}
MSS	F	22.3^{c}	41.2^{b}	52.0^{a}
	M	32.4^{b}	40.1^{b}	60.0^{a}
	G	–	56.0	58.0

Key: see Table 1. Means in a row having different superscripts (a, b and c) are different ($P < 0.05$).

Table 9
Means of Alpaca traits by sex

	F	*N*	M	*N*	C	*N*
BW (kg)	65.0^{b}	284	63.4^{b}	159	71.9^{a}	50
MFD (μm)	27.7^{b}	332	26.8^{b}	198	32.4^{a}	55
SD (μm)	6.5^{b}		6.3^{b}		7.8^{a}	
CV (%)	23.4		23.5		24.0	
PF (%)	30.5^{b}		27.2^{b}		53.5^{a}	
CF (%)	69.5^{a}		72.6^{a}		46.5^{b}	
AC (°/mm)	33.5^{a}		33.9^{a}		28.4^{b}	
CSD (°/mm)	31.0^{a}		32.0^{a}		27.9^{b}	
MED (per 10,000)*	1761	138	1720	110	1810	19
OBJ (per 10,000)*	371		356		463	
LSY (%)	89.6	331	90.0	198	90.3	55
MSL (mm)	109.8^{b}	331	129.0^{a}	197	109.9^{b}	55
LSD (mm)	7.5		8.0		8.4	
LCV (%)	7.0^{a,b}		6.4^{b}		7.5^{a}	
ADJ MSL (mm)	109.8^{b}	141	128.2^{a}	86	114.5^{b}	37
ADJ LSD (mm)	7.7		8.1		8.9	
ADJ LCV (%)	6.9		6.5		7.5	
MSS (N/ktex)	49.6^{b}	331	49.2^{b}	198	56.9^{a}	55
SSD (N/ktex)	17.1^{b}		16.3^{b}		22.6^{a}	
SCV (%)	38.2^{b}		38.0^{b}		43.2^{a}	
POB, tip (%)	30.4^{a}	332	35.4^{a}	198	21.1^{b}	55
POB, middle (%)	52.1^{b}		48.9^{b}		59.8^{a}	
POB, base (%)	17.1		15.6		19.1	
RTC (kPa)	5.4	330	5.4	194	5.6	51

Key: see Table 1. Means in a row having different superscripts (a and b) are different ($P < 0.05$).
* NW and NLF only.

Finally, strength differences were not apparent between the two castrate age groups.

3.3. Effects of sex

The main effects of sex are presented in Table 9 as unadjusted means. Most traits were not different between female and male. However, the smaller (and older) population of castrates tested were heavier and produced coarser, more variable (in terms of fineness) fibers having higher prickle factors (lower comfort factors), lower fiber curvature, and greater strength than fibers from female and male animals. This table also indicates that the larger and older population of females tested produced shorter (109.8 mm versus 129.0 mm, $P < 0.05$) fibers than the males. As samples from yearling castrates were absent, it was not possible to estimate least squares means for all three sex categories adjusted for age, region, and color. Consequently, Table 10 lists the least squares means for the females and males only. After adjustment, the only fiber characteristic significantly different between females and males is staple strength (38.7 N/ktex versus 44.5 N/ktex, $P < 0.05$). The lower strength of female Alpaca is possibly associated with the animal reproductive cycle of females ≥2-year-old (Hunter et al., 1990).

3.4. Effects of age

Most of the trends observed in Table 11 appear to be intuitively correct given current knowledge of other fiber growing species. This table quantifies the magnitude of the effects of age for female and male Alpaca (castrates not included). As Alpacas age, their body weights, fiber diameters and associated variabilities (but not CV), prickle factors (percentage of fibers coarser than 30 μm), percentage of medullated and objectionable fibers, laboratory scoured yield and staple strength (and associated variability) all increase. Interestingly, Alpaca from the youngest category of animals had the most tip breaks. In contrast, most breaks in the Alpaca from mature animals occurred

Table 10
Least squares means of Alpaca traits by sex (female and male only)

	F	M
BW (kg)	57.9	59.8
MFD (μm)	26.7	27.1
SD (μm)	6.6	6.5
CV (%)	24.7	24.0
PF (%)	27.0	29.4
CF (%)	73.0	70.6
AC (°/mm)	33.4	32.8
CSD (°/mm)	31.9	32.1
MED (per 10,000)*	1586	1569
OBJ (per 10,000)*	342	323
LSY (%)	89.1	89.4
MSL (mm)	121.2	126.7
LSD (mm)	9.0	8.4
LCV (%)	7.5	6.8
ADJ MSL (mm)	112.5	126.2
ADJ LSD (mm)	9.8	89
ADJ LCV (%)	8.4	7.2
MSS (N/ktex)	38.7[b]	44.5[a]
SSD (N/ktex)	15.1	16.5
SCV (%)	43.6	42.7
POB, tip (%)	39.5	41.9
POB, middle (%)	46.9	45.8
POB, base (%)	13.5	12.3
RTC (kPa)	5.4	5.4

Means in a row having different superscripts (a and b) are different ($P < 0.05$).
* NW and NLF only.

Table 11
Least squares means of Alpaca traits by age (female and male only)

	1	2	>2
BW (kg)	47.6[c]	59.8[b]	69.0[a]
MFD (μm)	24.3[c]	26.5[b]	30.1[a]
SD (μm)	6.1[c]	6.5[b]	7.1[a]
CV (%)	25.0[a]	24.4[a]	23.6[b]
PF (%)	17.3[c]	25.9[b]	41.4[a]
CF (%)	82.7[a]	74.1[b]	58.6[c]
AC (°/mm)	34.6[a]	33.7[a]	31.0[b]
CSD (°/mm)	34.0[a]	32.6[a]	29.4[b]
MED (per 10,000)*	1212[b]	1454[b]	2067[a]
OBJ (per 10,000)*	222[b]	321[b]	454[a]
LSY (%)	88.4[b]	89.0[b]	90.4[a]
MSL (mm)	132.2[a]	135.8[a]	103.8[b]
LSD (mm)	9.6[a]	9.0[a]	7.4[b]
LCV (%)	7.4	6.9	7.2
ADJ MSL (mm)	131.3[a]	119.8[a]	107.0[b]
ADJ LSD (mm)	12.2[a]	8.9[b]	7.0[c]
ADJ LCV (%)	9.2[a]	7.4[a,b]	6.8[b]
MSS (N/ktex)	27.7[c]	41.2[b]	56.0[a]
SSD (N/ktex)	13.2[b]	15.5[b]	18.7[a]
SCV (%)	48.7[a]	42.3[b]	38.3[c]
POB, tip (%)	55.2[c]	42.8[b]	24.2[a]
POB, middle (%)	38.2[b]	44.5[b]	56.4[a]
POB, base (%)	6.7[b]	12.8[b]	19.3[a]
RTC (kPa)	5.3	5.5	5.4

Means in a row having different superscripts (a, b and c) are different ($P < 0.05$).
* NW and NLF only.

in the middle of the staple. The implication is that strength is most likely to result in a processing problem (excessive fiber breakage) when fine Alpaca from yearling animals is used. In contrast, comfort factor decreases, as does fiber curvature, and staple length with increasing age. Resistance to compression appears to be insensitive to age, the latter observation being unexpected given the small but significant decrease in mean fiber curvature.

3.5. Variations in fleece color

Alpaca breeders and show judges spend considerable time and effort subjectively assessing the relative merits of Alpacas of different colors. Unfortunately, the sample obtained in this study contained only small numbers of some colors (NRG and NSG) and castrates were not represented at all in one age and some color categories. To avoid possible confusion that reporting of actual means might cause, least squares means were again estimated for each trait after adjusting for sex (male and female only) and age. These means are presented in Table 12. Generally, differences attributable to color were small. However, significant differences were present for most traits (MED, OBJ, MSL, and POBM being the exceptions). Animals producing NW fibers were heavier (60.3 kg versus 57.1 kg, $P < 0.05$) than those producing NLF fibers, all other colors being intermediate. The NW fibers were the finest with NB, NBR, and NSG being coarser (>3.5 μm, $P < 0.05$). Variability of fiber diameter (SD), PF, CF and AC followed the same (expected) trend as MFD. The LSY for all colors was high (>88%) with differences among colors being small (≤2.2%). Although the MSL was not different between colors, LSD and LCV for NRG tended to be higher than other colors (no explanation is offered). The smaller number of samples in the ADJ MSL data set resulted in significant differences among colors, NB being the longest and NRG being the shortest and least uniform (137.1 mm versus 110.8 mm and 7.3% versus 11.0%, $P < 0.05$, respectively). Mean strength values were all high and adequate for pro-

Table 12
Least squares means of Alpaca traits by color

	NB	*N*	NBR	*N*	NF	*N*	NLF	*N*	NRG	*N*	NSG	*N*	NW	*N*
BW (kg)	58.2[a,b]	39	59.8[a,b]	69	58.4[a,b]	89	57.1[b]	66	58.5[a,b]	17	59.6[a,b]	28	60.3[a]	135
MFD (μm)	29.5[a]	50	28.5[a]	82	26.1[b]	96	25.4[b,c]	80	25.7[b]	23	28.5[a]	30	25.0[c]	169
SD (μm)	7.0[a,b]		6.8[a,b]		6.2[c]		6.1[c]		6.4[b,c]		7.3[a]		6.0[c]	
CV (%)	23.8[b]		23.8[b]		23.8[b]		24.0[b]		25.1[b]		25.8[a]		24.1[b]	
PF (%)	41.1[a]		34.5[a]		23.9[b]		21.8[b]		23.2[b]		33.7[a]		19.2[b]	
CF (%)	58.9[b]		65.5[b]		76.1[a]		78.2[a]		76.8[a]		66.3[b]		80.8[b]	
AC (°/mm)	28.3[c]		30.5[b]		34.4[a]		35.9[a]		34.5[a]		31.5[b]		36.7[a]	
CSD (°/mm)	29.4[d]		29.7[d]		32.8[a,b,c]		33.3[a,b]		34.2[a,b]		30.9[c]		33.7[b]	
MED (per 10,000)[*]	–		–		–		1548	80	–	–	–		1607	168
OBJ (per 10,000)[*]	–		–		–		321		–		–		344	
LSY (%)	90.2[a,b]	50	89.9[a,b,c]	82	90.4[a]	96	89.0[b,c]	80	88.2[b,c]	23	88.1[c]	30	89.0[b,c]	168
MSL (mm)	119.2	50	130.4	82	121.2	96	123.2	80	127.1	23	122.0	30	124.3	167
LSD (mm)	8.1[a,b]		9.1[a,b]		7.9[b]		8.5[a,b]		10.0[a]		9.0[a,b]		8.2[a,b]	
LCV (%)	7.1[b]		7.2[b]		6.6[b]		6.9[b]		8.7[a]		7.0[b]		6.7[b]	
ADJ MSL (mm)	137.1[a]	19	124.9[a,b]	41	114.3[b,c]	35	114.6[b]	34	110.8[a,b,c]	8	105.2[b,c]	8	128.6[a,b,c]	82
ADJ LSD (mm)	9.8[a,b]		9.4[a,b]		8.7[b]		9.1[a,b]		12.0[a]		7.6[b]		9.0[a,b]	
ADJ LCV (%)	7.3[b]		7.4[b]		7.4[b]		7.8[b]		11.0[a]		7.0[b]		6.8[b]	
MSS (N/ktex)	39.0[a,b]	50	39.8[b]	82	43.3[a,b]	96	45.6[a]	80	37.2[a,b]	23	42.8[a,b]	30	43.7[a,b]	168
SSD (N/ktex)	18.0[a]		16.5[a,b]		16.2[a,b,c]		16.4[a,b,c]		12.9[c]		15.8[a,b,c]		14.9[b,c]	
SCV (%)	49.3[a]		46.7[a,b]		41.3[c]		40.4[c]		43.2[a,b,c]		41.2[b,c]		39.9[c]	
POB, tip (%)	41.0[a,b]		44.4[a]		41.3[a,b]		39.2[a,b]		39.9[a,b]		43.6[a,b]		35.6[b]	
POB, middle (%)	46.8		45.5		43.1		42.6		49.5		48.5		48.5	
POB, base (%)	12.4[a,b]		10.2[b]		15.6[a,b]		18.2[a]		10.8[a,b]		7.9[b]		15.4[a,b]	
RTC (kPa)	5.0[c]	50	5.3[b,c]	82	5.5[a,b]	92	5.6[a,b]	79	5.3[b,c]	23	5.4[b]	30	5.7[a]	168

Key: see Table 1. Means in a row having different superscripts (a, b and c) are different ($P < 0.05$).
[*] NW and NLF only.

cessing, and differences were relatively small with NLF being stronger than NBR (45.6 N/ktex versus 39.8 N/ktex, $P < 0.05$, respectively). Interestingly, RTC of the NW Alpaca was higher than for NB (5.7 kPA versus 5.0 kPA, $P < 0.05$) which was in line with the NW fibers being finer and having higher AC (i.e., higher crimp frequency).

Due to the fact that some of the color categories contained relatively few samples, the question remains as to how reproducible these results would be. Obviously, a balanced and larger data set would have been more desirable and would probably have provided more reliable estimates.

3.6. Correlations between traits

Having discussed differences in fiber traits attributable to sex, age, and color, it remains to report how the traits themselves are related. Table 13 lists the Pearson correlation coefficients between selected animal and fiber traits that will help provide a better understanding of the likely results of selecting for a particular trait. AGE was positively and significantly correlated with BW, MFD, LSY, and MSS and negatively and significantly correlated to AC and MSL. The correlation between AGE and RTC was not significant ($P > 0.3$). As animals age, BW, MFD, MSS, and even LSY increase, AC and MSL decrease and RTC is unaffected. These trends seem intuitively correct (with the possible exception of RTC) and are somewhat similar to trends observed for sheep (Brown et al., 1968) and Angora goats (Lupton et al., 1996) as are many of the correlations listed in Table 14. The MFD, LSY, MSS, and RTC are all correlated positively with BW, whereas larger BW are associated with lower values of AC and MSL. This latter negative correlation would not be expected for wool (Shelton and Lewis, 1986). The highest reported r-value was a negative correlation between MFD and AC, i.e., as fibers become coarser, curvature decreases, and crimp becomes bolder. The MFD was also negatively correlated with the MSL. This observation does not match those made between

Table 13
Pearson correlation coefficients between selected Alpaca animal and fiber traits

	BW	MFD	AC	LSY	MSL	MSS	RTC
AGE	0.5816	0.4751	−0.2775	0.1075	−0.3935	0.4537	0.0430
P	0.0001	0.0001	0.0001	0.0093	0.0001	0.0001	0.3034
N	493	585	585	584	584	584	575
BW		0.5318	−0.3758	0.1881	−0.3852	0.4435	0.2062
P		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
N		493	493	493	492	493	484
MFD			−0.8552	0.2401	−0.2961	0.3967	0.0732
P			0.0001	0.0001	0.0001	0.0001	0.0793
N			585	584	583	584	575
AC				−0.2299	0.1183	−0.2641	0.1071
P				0.0001	0.0042	0.0001	0.0102
N				584	583	584	575
LSY					0.0081	0.0879	−0.0124
P					0.8459	0.0337	0.7663
N					583	584	575
MSL						−0.5501	−0.0706
P						0.0001	0.0174
N						583	574
MSS							0.0620
P							0.1377
N							575

Key: see Table 1.

Table 14
Tristimulus values, brightness, and yellowness indices for natural white Alpaca samples ($N = 183$)

Item	Mean	SD	CV	Minimum	Maximum
X	61.60	4.35	7.07	42.80	70.35
Y	63.52	4.65	7.32	43.03	73.05
Z	60.14	5.42	9.00	34.85	71.05
YIE	18.68	2.60	13.93	12.74	34.62
Y–Z	3.38	1.47	43.66	−0.79	8.58

Key: X, Y, Z = red, green, and blue tristimulus values; Y = brightness; YIE = yellowness index; (Y–Z) = yellowness.

Table 15
CIE tristimulus values and color differences (ΔE) for colored Alpaca samples

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

Key: L^*, a^*, b^* = CIE tristimulus values. ΔE = CIELAB color difference.

different breeds of sheep in which the coarser breeds generally grow longer wool. However, it does match the within-breed observations of fine-wool Rambouillet sheep (Shelton and Lewis, 1986). This negative correlation is also different than that reported by Wuliji et al. (2000) 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 tend to be cleaner (higher LSY) and stronger. In the populations tested in New Zealand and the USA, MFD and RTC were not significantly correlated ($P = 0.08$ in the present study). This was not entirely predictable. In wool, for example, finer fibers tend to have more crimp, which 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 the RTC ($r = 0.11$), but is negatively correlated with LSY and MSS. The correlations between LSY and MSL, MSS, and RTC are all very low although the relationship between LSY and MSS was significant ($P < 0.05$). The MSL was shown to be negatively and quite highly correlated with MSS and lowly correlated with RTC. Finally, MSS and RTC were not significantly correlated.

3.7. Color measurements

Five hundred and forty-four samples were measured using the colorimeter. Of these, 183 were natural white and 361 colored. Table 15 summarizes the tristimulus values, brightness, and yellowness indices for the 183 white samples. In the Commission Internationale de l' Eclairage (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, the complete range of brightness values was obtained. A range of values of (Y–Z) for scoured and carded US white wool has been reported to be 3–10 (Cameron et al., 1999). In contrast, scoured New Zealand and Australian wools are in the range 0–4 (Cottle et al., 1992). The mean (Y–Z) for all white Alpaca samples was 3.38, demonstrating that on average they are as white as some of the whitest wools in the world. The YIE values for scoured and carded wools range from 20 to 28, so again the reported mean value for these Alpaca samples of 18.68 indicates they appear exceptionally white.

Wide ranges in yellowness and brightness exist for nominally white Alpaca samples. Instrumentation could be very useful for establishing white lines of Alpaca fiber based on measures of brightness and yellowness.

Table 15 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 mean 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 these color measurements is that a great deal of variability exists in these three major color groups. Instrument measurement of individual fleeces has the potential to become a very effective tool for establishing uniform color lines in the Alpaca.

4. Conclusions

The primary objective of this study was to produce a comprehensive profile of the properties of fiber grown by Huacaya Alpacas representative of those currently resident in the USA. This objective was achieved. With one major exception (LSY), the measured characteristics exhibited considerable variability, the most variable traits (CV > 60%) being PF, MED, OBJ, and POB. Differences attributable to sex were minimal, MSS being the lone exception. Males produced stronger fiber than females. In contrast, differences due to age were apparent in nearly every trait measured, LCV and RTC being the only two exceptions. Differences in traits attributable to color were numerous but relatively small in magnitude compared to the differences between age categories. In common with sheep and Angora goats, Huacaya Alpacas have been shown to produce fibers having broad ranges in many of the characteristics that are important for textile processing and end use determination. Thus, very fine Alpaca (with low PF) would be an ideal raw material for making lightweight, soft fabrics that can be worn next to the skin without causing discomfort while the coarser grades may be manufactured into durable rugs and carpets. The bulk of the fiber produced between these extremes is well suited for knitted sweaters and cardigans. The relative abundance of colored Alpacas further adds to the natural versatility of this fiber. Instrument measurement of color could be used to produce uniform color lines of Alpaca, if in fact this was desirable. Lack of uniformity in natural colors of Alpaca is considered attractive by some consumers.

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References

Alpaca Registry, 2004. http://www.alpacaregistry.net/resources/statistics/census.htm (accessed October 11, 2004).

ASTM D 584–96, 2003. Standard test method for wool content of raw wool-laboratory scale. Annual Book of ASTM Standards, Sec. 7, vol. 07.01. American Society for Testing and Materials, West Conshohocken, PA, pp. 187–192.

ASTM E313–96, 1998. Standard practice for calculating yellowness and whiteness indices from instrumentally measured color coordinates. Annual Book of Standards. vol. 06.01. American Society for Testing and Materials, West Conshohocken, PA, pp. 721–725.

Australian/New Zealand TX 12 Working Group, 2000. Working Draft—Measurement of Fibre Curvature.

Australian Standard 3535, 1988. Wool-Method for the Measurement of Resistance to Compression. Standards Association of Australia, North Sydney, NSW.

Blakeman, N.E., Lupton, C.J., Pfeiffer, F.A., 1991. Strength and resistance to compression of U.S. wools. Sheep Res. J. 7 (2), 4–7.

Brown, G.H., Turner, H.N., Dolling, C.H.S., 1968. Vital statistics for an experimental flock of Merino sheep. V. The effects of age of ram, maternal handicap, and year of measurement on 10 wool and body characteristics for unselected rams. Aust. J. Agric. Res. 19, 825–835.

Cameron, B.A., Brown, D.M., Stobart, R.H., 1999. The clean color of U.S. wool fiber comparison of scoured and carded wools. Sheep Goat Res. J. 15 (3), 154–158.

Castellaro, G.G., Garcia-Huidobro, J.P.A., Salinas, P., 1998. Alpaca liveweight variations and fiber production in Mediterranean range of Chile. J. Range Manage. 51 (5), 509–513.

Cottle, D.J., Zhao, W., Jones, J.C., 1992. Experiments to promote colour change in wool. J. Chem. Tech. Biotechnol. 55, 351–354.

Edmunds, A.R., Sumner, R.M.W., 1996. Further data on the use of OFDA for estimating raw wool bulk. IWTO Tech. and Stand. Comm. Meet., Nice, December 1996 (Report 7).

Hunter, L., 1980. The effects of wool fibre properties on processing performance and yarn and fabric properties. In: Proceedings of Sixth Quin. Int. Wool Text. Res. Conf., vol. 1, pp. 133–193 (contains 750+ references).

Hunter, L., van Wyk, J.B., de Wet, P.J., Grobbelaar, P.D., Pretorius, P.S., Morris, J. de V., Leeuwner, W., 1990. The effects of nutritional and lambing stress on wool fibre and processing characteristics. In: Proceedings of Eighth Quin. Int. Wool Text. Res. Conf., vol. II, pp. 145–156.

IWTO-30, 1998. Determination of Staple Length and Staple Strength. International Wool Textile Organisation Specification, The Woolmark Company, Ilkley, England.

IWTO-47, 2000. Measurement of the Mean and Distribution of Fibre Diameter of Wool Using an Optical Fibre Diameter Analyser (OFDA). International Wool Textile Organisation Specifications, The Woolmark Company, Ilkley, England.

IWTO-57, 1998. Determination of Medullated Fibre Content of Wool and Mohair Samples by Opacity Measurements Using an OFDA. International Wool Textile Organisation Specifications, The Woolmark Company, Ilkley, England.

Lupton, C.J., Huston, J.E., Holloway, J.W., Warrington, B.G., Waldron, D.F., Thompson, P.V., Pfeiffer, F.A., Qi, K., 1996. Animal performance and fleece characteristics of Angora goats maintained on western and southern Texas rangeland. J. Anim. Sci. 74, 545–550.

Lupton, C.J., Pfeiffer, F.A., Dooling, A.R., 1999. Prediction of cashmere style using objective fiber measurements. Sheep Goat Res. J. 15 (1), 1–4.

Lupton, C.J., Pfeiffer, F.A., Blakeman, N.E., 1993. Economic impact of pre-sale fiber measurements on prices paid for wool. Sheep Res. J. 9, 135–137.

McGregor, B.A., 2002. Environmental, nutritional, and management influences on quality and production of mohair and cashmere. In: Proceedings of Sixth International Conference on Goats, vol. 1, pp. 285–299.

Pumayalla, A., Leyva, C., 1988. Production and technology of the Alpaca and vicuna fleece. In: Proceedings of the First International Symposium on Specialty Fibres, DWI, Aachen, pp. 234–241.

SAS, 2000. Statistical Analysis System Release 8.2. SAS Institute Inc., Cary, NC.

Shelton, M., Lewis, R., 1986. Ram performance testing (in Texas). A review and evaluation. Tex. Agric. Exp. Sta. Res. Cent. Tech. Rep., 86–3.

Wuliji, T., Davis, G.H., Dodds, K.G., Turner, P.R., Andrews, R.N., Bruce, G.D., 2000. Production performance, repeatability and heritability estimates for live weight, fleece weight and fiber characteristics of Alpacas in New Zealand. Small Rumin. Res. 37 (3), 189–201.