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Evaluation of fiber diameter and correlated fleece characteristics of an extreme fine alpaca strain farmed in Missouri

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Abstract

Data recordings of animal breeding, fleece production, and fiber characteristics in an alpaca herd were analyzed and presented. A selective mating strategy was applied while establishing an extremely fine fiber alpaca strain at Victory Farm over 10 years. The herd was expanded from ten females and five males to 200 head. All animals were recorded for sires, dams, and registered pedigree, birth weight, weaning weight, shearing weight, and fleece weight. Mid-side flank fleece samples were harvested for Optical-based Fibre Diameter Analyser (OFDA) fiber characteristics, including mean fiber diameter, length, and curvature. Live weight, fleece weights, and fiber characteristics were analyzed using SAS® GLM procedures. Mean birth weight, weaning weight, mixed age shearing weight, fleece weight, fiber diameter, coefficient of fiber diameter variation, fiber length, and fiber curvature were 6.82 kg, 25.27 kg, 48.84 kg, 0.85 kg, 16.67 µm, 25.2%, 64.6 mm, and 56.9 deg/mm, respectively. In addition, the finest 25 percent of the herd's fleeces were tested and found to have an average fiber diameter of 14.17 µm, which was within vicuna fiber diameter ranges. These characteristics did not significantly increase with age. Heritability estimates for the fleece weight and fiber diameter, length, and curvature were 0.40, 0.65, 0.29, and 0.50, respectively. The average fiber diameter measurements of the herd at Victory Farm were significantly ($p < 0.001$) finer than the comparison herds. This study found that strict selective breeding is effective for genetic gains in ultralow fiber diameter and fleece quality in an extremely fine fiber alpaca strain.

Keywords: *Vicugna pacos*, alpaca strain, extremely fine, selective breeding, heritability

Introduction

Although camelids are indigenous to the Andean highlands of South America, now they are distributed in many parts of the world. The alpaca (*Vicugna pacos*) is the most numerous fiber-producing member of the four South American camelid species: llama, guanaco, alpaca, and vicuna (Kadwell et al., 2001). Two types of alpacas have been introduced into the United States, namely, huacaya and suri; however, the majority of alpacas (80%) are huacaya. Huacaya fleece is characterized as short, dense, crimpy, and woolly compared to the suri, which is described as silky, lustrous, long, and with pencil locks (Wuliji et al., 2000). Whereas Peru owns 75 percent of the alpaca population and produced about 90 percent of the world's camelid fiber in the past (Morante et al., 2009), the alpaca population introduced into nonnative regions has increased steadily in the last 30 years, especially in Australia, Canada, the United Kingdom, New Zealand, and the US. Alpacas are becoming an important specialty fiber production livestock species in these regions beyond the South American Andes. The alpacas registered to the Alpaca Registry, Inc. (ARI) in the US from 1986 to 2017 have increased to 255,128 head, including both huacaya and suri breeds, and the total number of fiber-growing camelids has been estimated at passing the 300,000 population mark in the US (Alpaca Consulting Services USA, 2017). Alpacas can be found in every state of the US and are farmed in various geographical environments, ranging from the desert to high mountain ranges (Wuliji, 2012). Coat color varies widely in camelids, ranging from white to black and various shades, including 22 natural color categories (Hoffman, 2003). Fleece production and fiber traits have been reported in some studies in the alpacas' native land (Pumayalla & Leyva, 1988; Frank et al., 2006; Montes et al., 2008; Morante et al., 2009; Cervantes et al., 2010). Animal husbandry and reproduction, especially fleece and fiber characteristics, were studied in these nonnative environments (Wuliji et al., 2000; McGregor, 2004; McColl et al., 2004). Profiles of the fiber characteristics of both huacaya and suri breeds farmed in the US have been reported (Lupton et al., 2006; Wuliji, 2012). Some of the literature and production records indicate that the introduced camelids had significantly improved body weight and fleece weight performance, whereas the fiber diameter had become coarser when grown on more nutritive grazing lands than the high Andes. Therefore, it is critical for camelid producers in these newer regions to conduct more intensive selection, maintain the camelid fiber's premier quality reputation, and retain its luxurious textile properties.

It was an owner's opportunistic assumption that there is an ample probability among the 300,000 camelids in the US to select and establish an extremely fine, fiber-growing alpaca strain. The owners of Victory Farm initiated an alpaca breeding venture in Braymer, Missouri, with just one dozen females and five males 10 years ago. By persistently acquiring breeding stock from fellow breeders and through restrictive selection within their animals, their herd size increased to 200 head in 2016. The goal was to establish an extremely fine alpaca herd by corrective breeding and intensive selection within the US camelid population that is also adapted to US environments. Therefore, this study was conducted to record, evaluate, and summarize the progress of breeding, production, and management practices established at Victory Farm. Animal production performance was presented for birth weight (BW); weaning weight (WW); shearing live weight (SW); fleece weight (FW); staple length (SL); and fiber characteristics, including fiber diameter (FD), fiber diameter variation (FDsd and FDcv), curvature (CUR), and medullation rate (MD).

Materials and methods

Animal husbandry, welfare, and health management

Victory Farm, owned by the Smith family, is located in Missouri at 39.5870° N, 93.7960° W, at an elevation of 233 m above sea level, with a landscape of rolling hills, with an annual average precipitation of 914 mm as rain and 406 mm as snowfall. Monthly average temperature ranges were recorded at −8 ºC to 3 ºC (January), 6 ºC to 18 ºC (April), 20 ºC to 32 ºC (July), and 7 ºC to 20 ºC (October). As of April 2016, the herd size had increased to 200 animals, including males, females, and crias. All animals were identified by implanted microchips for pedigrees, parentage, and breeding society registrations. The Veterinary Genetic Laboratory at the University of California, Davis provided the parentage and genetic marker test.

Animals were grazed as a mixed-age herd on pastures during warm seasons and fed on dry feeds under shelter during the winter months. Pasture plant species on the farm are a mixture of grasses and legumes, including fescue, orchard, brome, bluegrass, and white clover. Animals were grazed on pastures and rotated more frequently and efficiently at a stocking rate of 10 head per acre. Adult males and females were penned and fed separately in a drylot during winter. High-quality forages, clean water, and mineral supplements were provided ad lib. Alfalfa hay containing 12 to 16% crude protein was fed to females, yearlings, and weanlings, whereas brome or orchard grass hay with 10% crude protein was fed to males during drylot feeding. Animals were regularly graded for body condition scores as nutrition and health status indicators. Animal welfare and health care were contracted with the local veterinary practitioner. A routine vaccination for recommended preventable illnesses was practiced, such as an injection of *Clostridium perfringens* type C + D and tetanus (CD&T) at annual intervals and an injectable dewormer (Noromectin®) at six-week intervals during seasons prevalent with internal parasites. Only crias were tested for BVD II (bovine viral diarrhea). Over 10 years of operation, the animal mortality rate was kept below 2%. Other animal welfare and health care was performed, such as timely inspection for eye infections, scours, and bloating as well as toenail trimming and tooth grinding at annual shearing operations. Also, waste and dung piles were regularly cleaned and removed from pens or holding areas.

Production, selection, and breeding

Animal selection criteria were set for three objective measurements and two subjective traits, namely, fiber diameter (FD, µm), staple length (SL, mm), curvature in degree (CUR, deg/mm), coat color, and fleece density. The first breeding age was normalized at three years or older for males and two years for females; however, a female can be bred at about 18 months old if her live weight reaches 45 kg. Most animals were fall bred and fall born; however, a small number of animals could be spring bred if they were a noncarrier or not a bearer from fall breeding. Breeding was practiced as a single-pair mating in pens. Studs were fed and managed in separate barns and halter-trained prior to breeding. In particular, young males were well conditioned for the breeding seasons and halter-trained before introducing them to the females in their pens. The breeding pair match-up was decided with reference to the offspring from previous mating allocations. Animals were recorded for breeding, pregnancy, birthing, health care, and treatment records. Regular animal performance records were made on-farm, including birth date, sex, sire and dam, pedigree, birth weight (BW), weaning weight (WW), shearing body weight (SW), and fleece weight (FW). Animal breeding, pedigree, and production performance data were submitted to Colorado State University (Fort Collins, CO) to generate breeding value estimates. Data was recorded in an Excel spreadsheet for retrieval, communication, storage, and analysis. Animal registry information included animal ID (microchip), pedigrees, health records, and fiber test records.

Animals were estimated for breeding values using the expected progeny difference (EPD), which was updated annually to serve as a reference for individual animal sire or dam selection. It is noteworthy that most of the ranking coincided well with the owners' choice of breeding allocations. As alpacas are self-induced ovulators, the estrus cycle occurs after breeding. Therefore, the female was reintroduced to a male seven days later but would reject mating if she was pregnant; otherwise, she would submit to breeding. The pregnancy was confirmed by observation of her "spitting off" for three consecutive weeks, and predicted cria due dates could then be placed on the birthing calendar. The gestation length averaged 345 d on-farm but was observed as early as 317 d to as late as 388 d for normal birthing. Newborn crias were weighed several times during the first week of birth, thus assuring that they were nursing and gaining weight. From weaning age, animals were trained for weighing, catching, and releasing as well as halter-training so they could develop an early interaction with humans and become less stressed by handling. The other daily routine tasks included checkups for expectant females and newborn crias, along with providing mineral supplements, food, and water.

Blood pack cell volume and cell type measurements

In 2017, blood samples were taken from 24 animals (12 males and 12 females, with each sex including four crias) representing the herd to determine blood pack cell volumes and blood cell profile survey measurements post-shearing. Blood samples were drawn from the jugular vein from the right side of the neck (about the C6 vertebra) using venipuncture fitted with a needle and collected into heparinized tubes (purple top). Blood samples were delivered to the Small Animal Research Facility Lab at Lincoln University (Jefferson City, MO) within four hours of collection. A number of blood volume and cell parameters, including white blood cell (WBC) count and types (i.e., neutrophil, lymphocyte, eosinophil, and monocyte), red blood cell (RBC) count, hematocrit (HCT%), and platelet concentration were examined using the HEMAVET® HV950 hematology instrument (Drew Scientific, Inc.).

Shearing, fleece classing, and fiber trait measurements

Animals were scheduled to shear annually in April. Animals were sorted into coat color groups and penned under shelter overnight to prevent overfeeding or wetting of the fleece. Before shearing, vegetable matter and dirt was brushed off the body fleece surface. The shearing floor space was cleaned and covered with a tarp/canvas sheet that was used for animal restraining and for fleece collections. Shearing started with the lighter shade fleeces, such as white, cream, tan, and light brown to dark brown. A professional alpaca shearer was contracted for shearing assisted by the owners/laborers. The shearing procedure followed an established alpaca shearing technique, using wool shearing cutters fitted on a conventional hand piece to conduct clipping, which is similar to the procedure described by Wuliji et al. (1992), namely, the animals were shorn lying on their side on a tarp/canvas sheet-covered floor, with their two hind legs tied to a wall. Electric clippers with a sheep shearing comb and cutters were used to conduct shearing, while an assistant held the alpaca by both front legs, stretching and rolling the alpaca to expose the unshorn side fleece for the shearer. The saddle (blanket) fleece part was shorn first, followed by the rest of the fleece coat. A small batch of mid-side fiber sample was collected from each animal for fiber trait measurements. The blanket and saddle fleece parts were weighed separately, recorded, bagged individually, labeled, and stored for further fiber classing, processing, and/or marketing. A regular fiber test was conducted at each shearing and tested by the Yocom-McColl Testing Laboratories Inc. (Denver, CO). Yocom-McColl uses the Optical-based Fibre Diameter Analyser (OFDA 100) to measure a set of traits, such as the fiber diameter in microns, which is the ASTM standard (D2252) for alpaca fiber. Fiber measurements included FD, FD standard deviation (FDsd), and FD coefficient of variation (FDcv), SL, F30 (percentage of fiber diameter greater than 30 micron), CF (comfort factor, calculated as 100 − F30), curvature (CUR), and percentage of medullation rate (MD). The Yocom-McColl fiber test laboratory also provides ranch summary statistics and individual fiber diameter histograms for owners' review or verification.

Specialty camelid fiber collection, measurement, and comparison

As a reference analysis, 15 fiber samples (dehaired) of Bactrian camel from Inner Mongolia and 17 fiber specimens of vicunas from private collectors and zoos were donated for this in-house study. These samples were prepared, measured, and compared for FD and staple length with the fiber from the extremely fine fiber animals (25%) from the Victory Farm herd in 2016 and 2017. Staple length was measured in mm, with five replicates. Fiber diameter was measured according to a standard microscopic method that measures 250 individual fibers randomly per specimen prep slide, following the standard ISO 137:2015 Wool - Determination of Fibre Diameter - Projection Microscope Method (2015). Eight of those vicuna fiber specimens were also tested at Yocom-McColl and validated for the accuracy of the test by microscope procedures, which showed a 99.9% agreement between the two methods. The FD, FDsd, FDcv, and SL of the extremely fine groups (2016 and 2017) were selected from the Yocom-McColl lab test results for comparison. The fiber test results of the Victory Farm herd (shearing 2016) are included in a multi-ranch reference comparison (Table 6).

Expected progeny difference and heritability estimate

The herd-expected progeny difference (EPD) and heritability (h^2) values were estimated using a data pool of the breeding group's herds, which Victory Farm had organized for the collaborative breeding program. The pedigree and performance data of 760 animals with 2,915 performance records were included in this analysis. The EPD was calculated for six traits, including FW, SL, FD, FDsd, CUR, and FD rate of change (Enns & Speidel, 2017). Heritability is the proportion of phenotypic variation in a trait and a measure of the degree to which a trait, such as FW or FD, is genetically determined. The expression h^2 was estimated as the proportion of the difference in performance that is explained by a transmittable genetic difference. Therefore,

h^2 will range from zero to 1, with a higher value associated with a larger genetic influence on the traits. Multiple trait evaluation procedures were applied to estimate the correlation coefficient (r) among these traits, which may have a positive or negative effect on each other.

Data analysis and presentation

Victory Farm alpaca herd data files for birth weight, weaning weight, and shearing weight were retrieved and pooled for data analysis and presentation. Data were analyzed and compared among production year, sex, and age groups for body weight as well as fleece and fiber characteristics. Fleece weight and fiber characteristics were pooled and analyzed on 1,230 records of 11 annual shearings (2007 to 2017). However, 1,021 observations were used for most traits, as some fleece weight or fiber characteristic measurements were either incomplete or missing for the production years 2007 and 2008. This resulted from the small herd size, so data from those years were excluded from the comparisons. There were 173 birth weight (2010 to 2016) and 166 weaning weight records available for this analysis. Shearing live weight (SW) records of 478 animals were available from 2014 to 2016, which were compared by age groups with their repeated measurements. The FD, FDcv, SL, F30, CUR, (deg/mm), and MD rates were provided as part of the systematic standard measurements by the Yocom-McColl test lab, except for the farm reference study specimens. Production performance data by year, age, and sex were extracted from the Victory Farm database. SAS® statistical procedures (i.e., GLM, ANOVA, CORR, and t-test) were used to process those data sets. The main effects were primarily compared for production year, sex, and age; however, the EPD calculation and h^2 estimates were adopted from the Victory Farm group breeding annual reports (Enns & Speidel, 2017).

Results and discussion

Fleece weight and fiber characteristics are summarized by production years in Table 1. There were several significant differences ($p < 0.05$) in SL, FD, FDcv, and CUR. The FW and SL decreased gradually in the past few years, whereas the FDcv slightly increased over time in the herd. There was no significant difference in the FW, except for the 2009 shearing, which was highly skewed due to the shearing regimen and the small number of animals. The measure for the CUR and F30 remained steady, with only a small fluctuation. Except in 2010, when there was a significant surge, the F30 regularly tested low (i.e., from 0.96 to 1.62%), which was interpreted as the average CF of the fleeces for the herd over all the years of the study, which ranged from 98.4 to 99.9%. The FD of the herd gradually decreased, while the number of animals in the herd increased, and the FD decreased significantly ($p < 0.05$) in production years 2016 and 2017.

The Victory Farm alpaca herd's cumulative FD measurements were plotted by production year (Figure 1). The mean FD of the herd decreased gradually and consistently from 2007 to 2017, while the herd size increased. The apparent annual average reduction in the FD was 0.21 microns per year in the last eight fleece measurements, which reduced the herd average FD to 16.58 and 16.68 in 2016 and 2017, respectively.

Table 1. Fleece weight (FW), staple length (SL), mean fiber diameter (FD), coefficient of fiber diameter variation (FDcv), percentage of fiber coarser than 30 micron (F30), and fiber curvature (CUR) measurements by production years

Year	Numbers	FW (kg)	SL (mm)	FD (µm)	FDcv (%)	F30 (%)	CUR (deg/mm)
2009	35	1.43^{n*}	87.4^{c}	18.02^{bc}	25.2^{abc}	1.43	57.61^{ab}
2010	59	1.11	75.2^{bc}	18.37^{cd}	25.5^{ab}	2.16^{n*}	53.17^{a}
2011	67	1.08	64.2^{ab}	18.19^{bc}	23.0^{a}	1.49	53.81^{a}
2012	68	1.04	65.5^{ab}	16.95^{a}	24.0^{ab}	1.13	57.81^{ab}
2013	77	0.85	57.2^{a}	17.03^{ab}	24.1^{ab}	1.03	61.49^{bc}
2014	168	0.83	56.7^{a}	17.13^{ab}	24.8^{abc}	1.05	58.15^{bc}
2015	143	0.78	57.5^{a}	17.36^{bc}	26.6^{bc}	1.32	53.87^{a}
2016	164	0.76	57.8^{a}	16.58^{a}	26.4^{bc}	0.96	57.66^{ab}
2017	171	0.73	59.9^{a}	16.67^{a}	27.2^{bc}	1.05	58.30^{bc}

^{abcd}: means bearing a different superscript differ within the column at the $p < 0.05$ level
^{n*}: significantly differed ($p < 0.05$) from the rest of the column

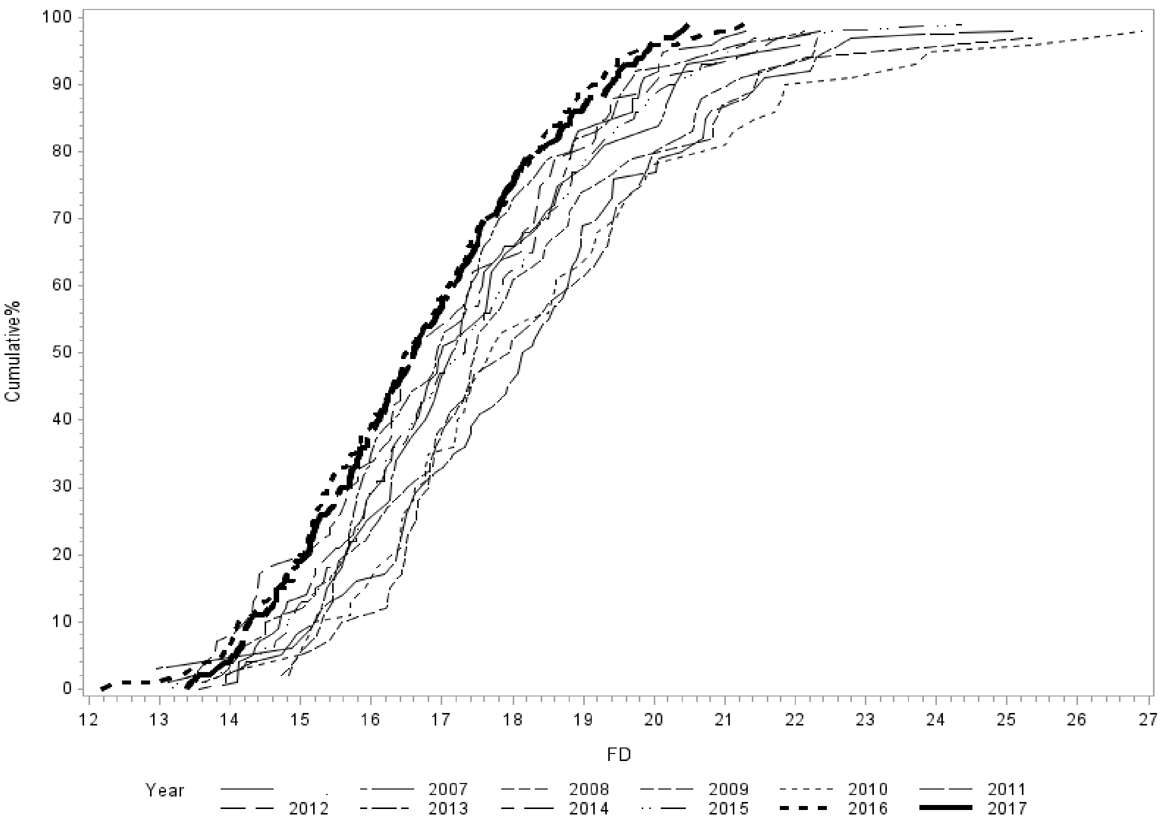

Figure 1. Scatter plot of individual animal FD measurements (cumulative percentage of the herd) in the Victory Farm alpaca herd by production year (2007 – 2017)

The herd average fiber diameter, staple length, fiber curvature, fiber diameter, and variation analysis by age group is shown in Figure 2. The effect of age was more pronounced on the SL, and the CUR decreased with increasing age. There was no difference in the SL by sex; however, for crias, the SL was reported to grow longer in the warm seasons than in the cold seasons in Peru (Quispe-Peña et al., 2014). Both the FD and FDcv in the herd showed minor fluctuations with increasing age, which was significantly less varied compared to other huacaya or suri alpacas (Wuliji, 2012). The FW and F30 fluctuated and slightly decreased with age, whereas the MD rose with age.

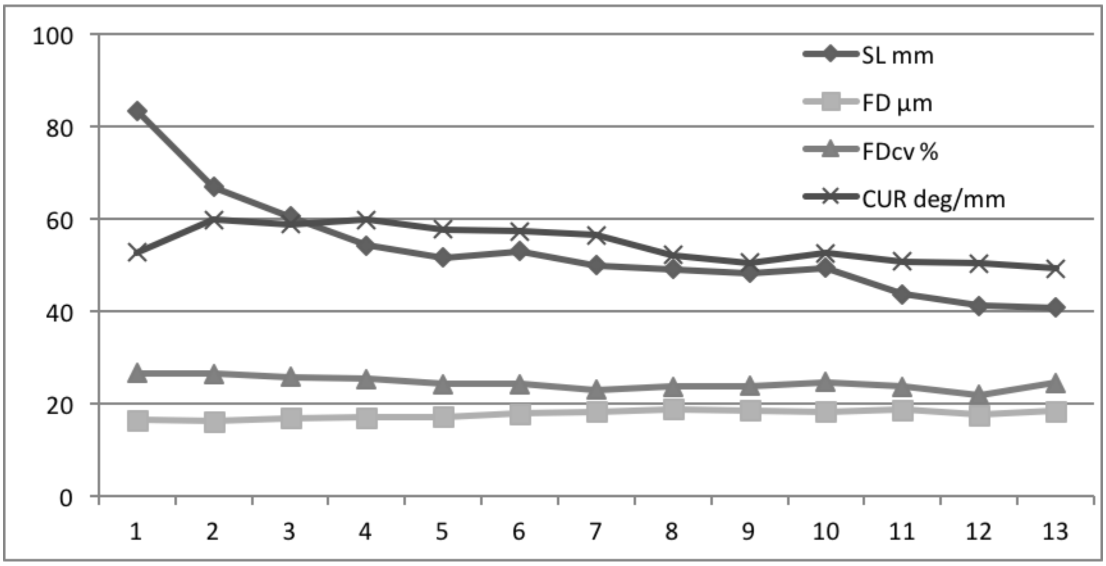

Figure 2. Staple length (SL), fiber diameter (FD) and diameter variation (FDcv), and fiber curvature (CUR) measurements in alpaca age groups.

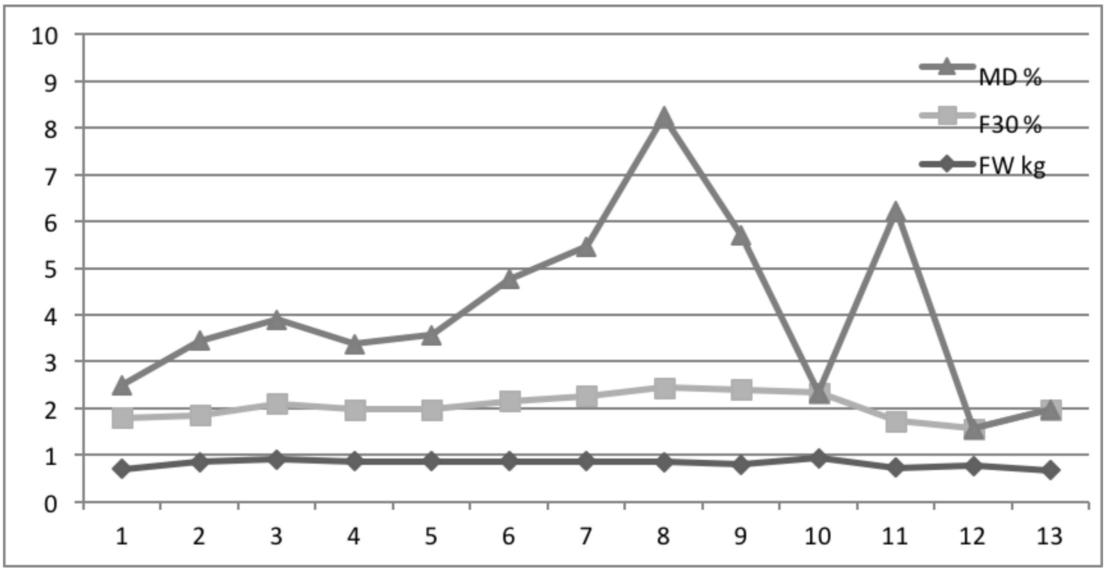

Figure 3. Measurements of fleece weight (FW), medullation (MD), and the percentage of fiber diameter (F30) coarser than 30 microns in alpaca age groups.

The herd average fleece weight, percentage of fiber diameter greater than 30 microns, and medullation rate analyzed by age group is shown in Figure 3. There were almost no changes in the FW and F30 measurements based on age; however, several significant ($p < 0.05$) surges in the MD corresponded only to the eight-year-old age group.

Fleece weight and fiber characteristics are summarized by sex in Table 2. There was no difference for the FW, SL, and CUR, but the FD, F30, and MD were higher for females than males, and the FDcv was coarser for males than females.

BW and WW were presented for birth years by sex, and the means were pooled (Table 3). There was no difference based on sex, but there was a small and significant difference in BW and WW recorded by birth years. However, there was a small but significant difference in the mean BW and WW by birth years, and both the BW and WW were higher for females than males. There were a number of significant positive or negative correlations among fleece weight and fiber characteristics (Table 4).

There was a significant and positive or negative correlation ($p < 0.01$) among all traits except MD with SL; there were no significant corrections with the FDcv. There were positive and significant correlations found among FW, SL, FD, F30, and MD, whereas there were some negative and significant associations between the FD and each of the following: FDcv, F30, FC, CUR, and CUR standard deviation (CURsd). Correlations among the FW, FD, FDcv, and CUR were of a similar magnitude to those found in previous analyses of US alpacas (Lupton et al., 2006; Wuliji, 2012).

Table 2. Fleece weight and fiber characteristic measurements compared by sex (pooled for years and ages)

Sex	Freq. No	FW (kg)	SL (mm)	FD (µm)	FDcv (%)	F30 (%)	FC (%)	CUR (deg/mm)	MD (%)
Female	576	0.84	60.0	17.59	24.7	1.39	98.61	56.3	2.1
Male	443	0.85	61.3	16.69	26.2	1.03	98.97	57.8	1.3
SD		0.29	18.8	2.05	4.6	1.16	1.16	10.8	5.9

Table 3. Birth weight (kg), weaning weight, and the mean weights of alpacas recorded for six consecutive years after birth

Birth weight (BW)	2010	2011	2012	2013	2014	2015	2016
Female BW	6.8^{ab}	6.5^{ab}	6.5^{ab}	6.5^{ab}	7.0^{ab}	6.3^{a}	7.5^{b}
Male BW	6.8	6.7	6.8	7.3	6.9	6.6	7.4
Mean BW	6.8^{ab}	6.6^{a}	6.7^{ab}	6.9^{ab}	7.0^{b}	6.4^{a}	7.4^{b}
SD	1.1	1.1	1.0	0.9	0.9	0.9	1.0
Weaning weight (WW)							
Female WW	23.5^{ab}	26.6^{b}	25.2^{bc}	26.8^{b}	29.8^{c}	22.2^{a}	27.9^{bc}
Male WW	21.8^{a}	25.5^{ab}	23.9^{ab}	25.1^{ab}	27.3^{bc}	22.8^{a}	26.3^{bc}
Mean WW	22.9^{ab}	25.9^{b}	24.7^{ab}	25.9^{b}	28.3^{bc}	22.5^{a}	26.7^{bc}
SD	2.5	3.2	1.9	3.3	3.7	3.8	3.5

^{abcd}: means bearing a different superscript differ within rows at the $p < 0.05$ level

The mean fiber diameter (FD), minimum and maximum variant, FD variations (FDsd and FDcv), and staple length (SL) measurements in specialty reference fibers are compared in Table 5. The mean FD was significantly lower in vicuna fiber compared to camel and alpaca fibers. The extremely fine alpaca fiber diameter measured 3.2 microns less than camel hair and only one micron coarser than vicuna fiber ($p < 0.01$). The FD measured for the reference vicuna fiber specimens was nearly the same as the saddle fleeces of vicunas examined in Peru (Quispe et al., 2014). However, the FD measured for extremely fine fiber groups of the Victory Farm herd in the 2016 and 2017 shearings consistently tested within the range (i.e., 14.15 and 14.29 µm, respectively) of the fiber diameter variation among the vicunas of South America.

The Victory Farm FD test results from 2016 were compared with results from eight randomly tested alpaca farms in the US (Table 6). The Victory Farm herd's average FD in 2016 was significantly ($p < 0.01$) finer than all of the eight alpaca farms (Wuliji, 2012). The FD of the Victory Farm herd ranked first in micron fineness, which was 4.74 µm, 6.10 µm, 7.82 µm, 8.81 µm, 8.96 µm, 10.26 µm, 12.35 µm, and 12.42 µm lower than the FD tested in the other farm herds, respectively.

Table 4. Correlation coefficient estimates among fleece weight and fiber characteristics in the alpaca herd

Traits	SL	FD	FDcv	F30	FC	CUR	CURsd	MD
FW	0.42**	0.22**	-0.14**	0.20**	-0.24**	-0.21**	-0.12**	0.16*
SL		-0.12**	0.18**	0.25**	-0.18**	-0.28**	-0.17**	-0.14
FD			-0.34**	0.59**	-0.55**	-0.63**	-0.53**	0.68**
FDcv				0.28**	-0.12**	0.16**	0.30**	0.06
F30					-0.79**	-0.53**	-0.36**	0.55**
FC						0.45**	0.32**	-0.46**
CUR							0.83**	-0.35**
CURsd								-0.23**

** indicates a significant association at the $p < 0.01$ level

Table 5. Comparison of the mean fiber diameter (FD), minimum and maximum variant, FD variations (FDsd and FDcv), and staple length (SL) measurements in specialty reference fibers (camel or vicuna fiber) with extremely fine selection groups (25%) of the Victory Farm herd for 2016 and 2017

Camelid Species	Numbers	FD (µm)	Minimum (µm)	Maximum (µm)	FDcv (%)	SL (mm)
Vicuna fiber	17	13.07^{a}	11.54	15.29	22.69^{a}	34.7^{a}
Extreme fine 2016	34	14.15^{b}	12.17	15.05	28.12^{b}	60.6^{b}
Extreme fine 2017	34	14.29^{b}	13.38	14.99	29.25^{b}	66.9^{b}
Camel fiber	15	17.43^{c}	15.35	21.09	31.83^{b}	80.0^{c}

^{abc}: means bearing a different superscript differ within the column at the $p < 0.01$ level

Table 6. Victory Farm (1) FD test results (2016) compared with eight alpaca farm results in the US

Farms	1	2	3	4	5	6	7	8	9
Animals	164	81	104	202	65	27	239	91	58
FD (µm)	16.58^{a}	21.32^{b}	22.68^{b}	24.40^{c}	25.39^{c}	25.54^{c}	26.84^{c}	28.93^{d}	29.00^{d}
SE	0.32	0.45	0.39	0.30	0.50	0.78	0.26	0.43	0.53

^{abc}: means bearing a different superscript differ within the row at the $p < 0.01$ level

Table 7. White blood cell (WBC) count, hematocrit (HCT), and cell types measured for cria and adult alpaca samples for the Victory Farm herd (2017)

Group		WBC (K/µL)	NE (%)	LY (%)	MO (%)	EO (%)	RBC (M/µL)	HCT (%)	PLT (K/µL)
Cria	8	9.44	63.18	12.22	23.85	0.62	13.56	29.65	179
Adult	16	10.67	83.29*	3.58*	11.98*	1.04	12.76	28.61	171
Total	24	10.26	76.59	6.46	15.93	0.90	13.03	28.95	174
SD		2.64	13.63	5.91	9.30	0.48	1.62	3.37	54

NE: neutrophils; LY: lymphocytes; MO: monocytes; EO: eosinophils; RBC: red blood cell count; PLT: platelet count; K = 1 thousand; M = 1 million; *cria and adult alpacas differed significantly at the $p < 0.05$ level

Blood cell counts and cell type measurements in a selected number of animals are shown in Table 7. There was no difference between the sexes for any of the blood parameters measured; however, there was a significant difference ($p < 0.05$) in the neutrophils (NE), lymphocytes (LY), and monocytes (MO) between the cria and adult. The overall means for the blood parameters were within normal ranges.

The average expected progeny difference in fleece weight, fiber characteristics, and accuracy estimates for the Victory Farm herd are listed in Table 8. The average accuracy of the six traits estimated was in the range from 19 to 76%, which were mostly negative values, except the mean curvature EPD and a large variation available for the selection traits and corrective breeding. Specifically, the average FD value in the EPD was −0.21 µm, but more than 25 percent of the individual animals in the herd were rated at −1.84 µm to −1.08 µm, with the FD reduction potentiality in the progeny estimated as being accurate in the 55 to 75% range.

Heritability and correlations among fleece weight and fiber trait estimates for extremely fine alpaca breeding herds are listed in Table 9. The estimate of h^2 and correlations among the listed traits did not change in the last three-year performance evaluation for the EPD (Enns & Speidel, 2017). The h^2 estimate indicated that the FD and CUR were highly (≥ 0.5) heritable traits, but the FW, FDsd, and SL exhibited only moderate levels of heritability (≤ 0.4). These results were closely comparable to published estimates for camelids (Wuliji et al., 2000; Gutierrez et al., 2009).

Table 8. Expected progeny difference (EPD) in fleece weight and fiber characteristics in the Victory Farm alpaca herd (2017)

EPD traits	Average	SD	Minimum	Maximum	Accuracy %
Fleece weight (kg)	−0.06	0.04	−0.07	0.10	19 - 66
Staple length (mm)	−0.83	4.65	−9.71	12.45	21 - 71
Mean curvature (deg/mm)	0.79	3.33	−10.21	7.51	24 - 74
Fiber diameter (μm)	−0.21	0.99	−1.84	3.94	25 - 75
FD standard deviation (μm)	−0.10	0.21	−0.51	0.77	22 - 71
FD rate of change (μm)	−0.01	0.09	−0.20	0.43	22 - 76

Table 9. Heritability (the values along the diagonal) and correlations among fleece weight and fiber traits estimated for group breeding herds (Enns & Speidel, 2017)

Fiber traits	FW	FD	FDsd	SL	CUR
FW	0.40	0.54	0.36	-	-
FD		0.65	0.75	0.58	−0.82
SL			0.39	-	-
FDsd				0.29	−0.82
CUR					0.50

The phenotypic correlation estimates (Table 4) for the FW and SL, and also for the FD and CUR, were in agreement with the current genetic correlation estimation, as provided in Table 9. The efficiency of selection and genetic gain in an extremely fine fiber diameter depends on the strength of heritability as well as correlations among the selection traits, such as the FD, FW, SL, CUR, and threshold-subjective traits. In addition to the strict selection and corrective mating in the herd, a tandem culling for some undesirable traits, such as unfitness, poor reproduction, coarse fiber, and high medullation, should support the long-term selection goals.

Conclusions

For the alpacas on the Victory Farm, the birth weight, weaning weight, and shearing weight were similar to the published camelid literature; however, the fiber weight and fiber characteristics of the Victory Farm herd were lower than typical huacaya and suri alpacas. Specifically, the fiber diameter, staple length, softness, and coat color traits appeared more similar to domesticated vicuna-like characteristics. The heritability, genetic, and phenotypic correlations among fleece and fiber traits were moderate to high for the major selection traits. Both the EPD values and production performance analysis indicated that there is a high probability and potential genetic gain in an extremely fine fiber diameter alpaca strain selection. This study indicated that strict selection and corrective breeding in the Victory Farm herd was highly effective for genetic gain in the fiber diameter trait needed to establish an extreme fine fiber alpaca strain.

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