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Genetic analysis of six production traits in Peruvian alpacas

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ABSTRACT

In this study a total of 6499 records were obtained for fibre diameter (FD) and coefficient of variation of FD (CV), 3283 records for greasy fleece weight (GFW), staple length (SL) and shearing interval (SI) and 1802 records of textile value index (TV) obtained from an experimental herd of alpacas exploited in the Peruvian Altiplano.
The estimated heritabilities were: 0.412 ± 0.015 (FD), 0.321 ± 0.013 (CV), 0.098 ± 0.016 (GFW), 0.070 ± 0.011 (SL), 0.061 ± 0.012 (SI) and 0.163 ± 0.017 (TV). No significant genetic correlation was found for the pairs FD-CV and CV-GFW whilst the pairs FD-GFW, FD-SI and FD-TV had significant genetic correlations of, respectively, 0.405 ± 0.081, −0.395 ± 0.078 and −0.746 ± 0.049. No significant correlations were found for SL except for the pair SL-SI (0.397 ± 0.099). The TV index also showed significant genetic correlations with CV of 0.125 ± 0.061 and with GFW of 0.490 ± 0.070. All estimates of permanent environmental effects (c^2) associated with the six analysed traits were statistically significant ranging from 0.008 for SI to 0.259 for CV. Total repeatability for the analysed traits was low for SI (0.069) and SL (0.090), moderate for TV (0.299) and GFW (0.316) and high for FD (0.578) and CV (0.579). The permanent environmental effect associated with CV is significantly correlated with those of the other traits except for FD. The permanent environmental effects associated with GFW and SL seemed to be basically the same (estimated correlation of 0.916 ± 0.062). The permanent environmental effect for TV is highly correlated with those associated with GFW (0.498 ± 0.058) and SL (0.750 ± 0.137). Expected selection response for TV was higher when FD was considered as selection goal instead of TV itself.
It would, therefore, be more efficient to use FD rather than empirical indices as selection criterion to increase textile value in Peruvian alpacas. The reported genetic parameters and correlation matrices can be useful to implement multitrait breeding value estimations for alpaca selection.

1. Introduction

Peru produces about 90% of the world camelid fiber (CONACS, 2004). The alpaca is the most important fibre producer of the South American camelidae species playing a major role in the maintenance of rural communities in the Andean area. In Peru alpacas are kept under very harsh conditions and traditional management. Two different breeds of alpacas, known as Huacaya and Suri, can be distinguished. The Huacayas have a crimpy and bulky fleece and the Suris grow a straight and compact fleece (Wuliji et al., 2000). With the successful introduction of the alpacas to various other regions such as Australia (Ponzoni et al., 1999; McGregor and Butler, 2004) or New Zealand (Wuliji et al., 2000) some attempts have been made at implementing a genetic improvement program for alpaca fibre production in the Peruvian Altiplano. The most recognised program is that run by PACOMARCA S.A. that has implemented a performance recording organisation, including the development of specific software and an experimental ranch applying state-of-the-art

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technology. The final goal of this performance recording organisation is to establish a sire selection program for fibre quality aimed at spreading the improvements to traditional herdsmen, thus increasing the profits from their activities as well as those of the textile industry.

There is increasing information about the sources of variation in alpaca fibre yield and quality including diameter attributes (Wuliji et al., 2000; McGregor and Butler, 2004; Lupton et al., 2006). However, information on genetic parameters affecting alpaca (Ponzoni et al., 1999; Wuliji et al., 2000; Frank et al., 2006) and llama (Wurzinger et al., 2006) fibre production is scarce and mostly limited to reports of the heritability of the traits and estimates of between-traits genetic correlation have not yet been published. In particular, although, estimates of genetic parameters are required to design effective genetic improvement programs, no genetic relationship between fibre diameter and its variability or usefulness of indices constructed to obtained an overall improvement of the textile value of the product have been ascertained in alpacas. The aim of this research is to estimate genetic parameters associated with the following alpaca production traits: fibre diameter (FD), coefficient of variation of FD (CV), greasy fleece weight (GFW), staple length (SL), shearing interval (SI) and textile value index (TV). The implications of the obtained results for the implementation of a sire selection program in Peruvian alpaca are discussed.

2. Materials and methods

2.1. Data

Production data and pedigree information were obtained from the experimental PACOMARCA S.A. ranch as registered in the performance recording software PACO PRO (http://www.pacomarca.com/pacomarca/paco_pro_en.htm), developed by PACOMARCA S.A., which can be used to gather relevant production and genealogical data. The PACOMARCA S.A. ranch was founded in 1992 and is located in the department of Puno (southeast Peru). It occupies approximately 1500 ha and lies at an altitude of 4060 m above sea level, on the Altiplano. In winter, the temperature goes down to −15 °C.

The analysed traits were fibre diameter (in µm; FD), coefficient of variation of FD (in %, CV), greasy fleece weight (in kg; GFW), fibre length (in cm; SL), shearing interval (in days; SI) and textile value index (in US$; TV). Mean fibre diameter (FD) was computed from washed samples after minicored and 2 mm snippets using an Optical fibre Diameter Analyser (OFDA, IWTO-47-95). Staple length (SL) was assessed on a single staple per individual. The individual SI's were computed as the time, in days, between two subsequent shearings. The textile value index (TV) is calculated as a linear combination of the profit of the different qualities of fibre of an individual fleece. The weight in kg of the different classes of fibre (Royal, <20.0 µm; Baby, 20.1–22.5 µm; SuperFine, 22.6–24.0 µm; Fine, 24.1–26.5 µm; Medium, 26.6–30.5 µm and Strong >30.5 µm) was weighted by its monetary value and corrected by the performance obtained after processing the fleece. The economic weights given to each of the qualities of fibre were, in US Dollars: 50 (Royal), 22 (Baby), 15 (SuperFine), 10 (Fine), 4 (Medium) and 1 (Strong).

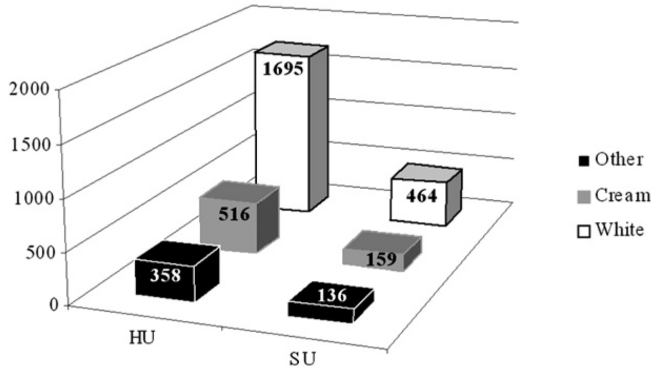

Fig. 1. Frequency of records of coat colour classes according to the breed of the individual: Huacayo (HU) and Suri (SU).

Records obtained from the PACO PRO database were edited in order to exclude animals with identification errors or ambiguous birth dates. The availability of age at recording was mandatory and ranged from 15 to 5111 days.

The number of individuals with production records was 2531 for FD and CV, 1821 for GFW, SL and SI, and 1402 for TV. Up to 77% of the individuals belonged to the Huacayo breed whilst the others were Suris. Animals were classified according to coat colour in three classes: white (65%), cream (20%) and other coat colour (15%). Fig. 1 shows the distribution of coat colour classes according to the breed of the individuals. Coat colour distributions within breeds were similar: 66% of Huacayos and 61% of Suris were white coated and 20% of the individuals in each breed were cream coated. These within-breeds frequencies are basically the same at the within-breed and sex level (not shown). In any case, 51% of the available individuals were white Huacayo.

Pedigree was traced back until foundation of the performance recording thus totaling 3328 animals in the pedigree. Final structure of the analysed data was dependent on the traits involved in each analysis (Table 1). The total number of records available per trait was as follows: 6449 for FD and CV, 3283 for GFW, SL and SI, and 1802 for TV.

2.2. Genetic analyses

Genetic parameters were estimated via a multitrait restricted maximum likelihood (REML) procedure applied to mixed linear models. The models fitted for genetic analyses included the following fixed effects: month-year of recording as contemporary group (41 levels), breed-colour (6 levels according to the three combinations between the two breeds, Huacayo and Suri, and the three coat classes, white, cream and others), sex (male or female) and the age at shearing in days as a linear and quadratic covariant. When a level of the contemporary group included less than five records, they were included in the closest temporal level.

Genetic analyses were carried out using a multivariate model involving FD, CV, GFW, SL, SI and TV. The linear animal model fitted was $\mathbf{y} = \mathbf{Xb} + \mathbf{Zu} + \mathbf{Wp} + \mathbf{e}$, with:

$$\begin{pmatrix} u \\ p \\ e \end{pmatrix} \approx N\left(\begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}, \begin{bmatrix} G & 0 & 0 \\ 0 & P & 0 \\ 0 & 0 & R \end{bmatrix} \right)$$

Table 1
Structure of data used for the estimation of genetic parameters for fibre diameter (in μm; FD), coefficient of variation of FD (in %, CV), greasy fleece weight (in kg; GFW), fibre length (in cm; SL), shearing interval (in days; SI) and textile value index (in US$; TV).

Structure of data	FD	CV	GFW	SL	SI	TV
Animals with record	2531	2531	1821	1821	1821	1402
Average number of records per animal	2.6	2.6	1.8	1.8	1.8	1.3
Sires with progeny in data	68	68	70	70	70	52
Average offspring per sire	30.7	30.7	25.5	25.5	25.5	15.8
Females with progeny in data	776	776	661	661	661	517
Sires with record and offspring	47	47	60	60	60	24
Females with record and offspring	774	774	595	595	595	461
Sire-offspring pairs	1920	1920	955	955	955	601
Female-offspring pairs	2448	2448	1675	1675	1675	810
Mean	23.0	24.0	2.136	11.4	433.4	27.1
Standard deviation	4.1	3.8	1.136	5.0	224.7	15.3

$\mathbf{G}=\mathbf{A}\otimes\mathbf{G_0}$, $\mathbf{P}=\mathbf{I_p}\otimes\mathbf{P_0}$, $\mathbf{R}=\mathbf{I_e}\otimes\mathbf{R_0}$, and $\mathbf{y}$ is the vector of observations, $\mathbf{X}$ the incidence matrix of fixed effects, $\mathbf{Z}$ the incidence matrix of animal effect, $\mathbf{W}$ the incidence matrix of permanent environmental effect, $\mathbf{b}$ the vector of unknown parameters for fixed effect, $\mathbf{u}$ the vector of unknown parameters for direct animal genetic, $\mathbf{p}$ the vector of unknown parameters permanent environmental, $\mathbf{e}$ the vector of residuals, $\mathbf{I_e}$ the identity matrix of equal order to the number of records, $\mathbf{I_p}$ the identity matrix of equal order to the number of permanent environmental subclasses, $\mathbf{A}$ the numerator relationship matrix, $\mathbf{R_0}$ the residual covariance matrix among measurements on the same animal, $\mathbf{G_0}$ the covariance matrix for additive genetic effects, $\mathbf{P_0}$ the covariance matrix for permanent environmental effects and $\otimes$ the Kronecker product.

All runs were carried out using the VCE v.5.0 program (Neumaier and Groeneveld, 1998).

3. Results

Average values of the analysed traits in the PACO PRO database were 23 μm for FD, 24.0% for CV, 2.136 kg for GFW, 11.4 cm for SL, 433.4 days for SI and 27.1 US$ for TV (Table 1).

Estimates of heritability and between-traits genetic correlations are given in Table 2. All the estimates of heritability were significant for $p<0.05$ and from low to moderately high ranging between 0.061 for SI to 0.412 for FD. No significant genetic correlation was found for the pairs FD-CV and FD-GFW whilst the genetic effect for CV was significantly correlated with that for GFW (0.405 ± 0.081). FD had significant and negative genetic correlations with SI (-0.395 ± 0.078) and TV (-0746 ± 0.049), respectively). Shearings interval (SI) had significant genetic correlations with FD (-0.395 ± 0.078). No significant correlations were found for SL except for the pair SL-SI (0.397 ± 0.099). Additionally, apart from the high and negative genetic correlation with FD, TV had significant genetic correlations with CV and GFW even though it was low for the pair TV-CV (0.125 ± 0.061) and for the pair TV-GFW it was moderate to high (0.490 ± 0.070).

Estimates of permanent environmental effects (c^2) associated with the six analysed traits, repeatibilities and correlations between them are given in Table 3. All the c^2 effects were statistically significant for $p<0.05$ and mainly low, ranging from basically 0 (0.008) for SI to 0.259 for CV. Repeatability was low for SI (0.069) and SL (0.090), moderate for TV (0.299) and GFW (0.316) and high for FD (0.578) and CV (0.579). The genetic additive component affecting the traits was larger than the corresponding permanent environment except for TV in which h^2 and c^2 reached similar values and particularly for GFW in which c^2 is more than twice h^2. The permanent environmental effect associated with CV is significantly correlated with those of the other traits except for

Table 2
Phenotypic variance (σ_p^2), heritabilities (on diagonal), between-traits genetic correlations (above diagonal) and their corresponding standard errors (in brackets) for six production traits in Peruvian alpacas.

	σ_p^2	FD	CV	GFW	SL	SI	TV
Fibre diameter (in μm; FD)	9.6	**0.412** (0.015)	0.032 (0.034)	0.116 (0.060)	0.102 (0.073)	−**0.395** (0.078)	−**0.746** (0.049)
Coefficient of variation of FD (in %; CV)	11.0		**0.321** (0.013)	**0.405** (0.081)	0.177 (0.081)	0.015 (0.078)	**0.125** (0.061)
Greasy fleece weight (in kg; GFW)	0.8			**0.098** (0.016)	−0.034 (0.129)	−0.132 (0.151)	**0.490** (0.070)
Staple length (in cm; SL)	12.9				**0.070** (0.011)	**0.397** (0.099)	−0.042 (0.104)
Shearing interval (in days; SI)	25,514.8					**0.061** (0.012)	0.177 (0.113)
Textile value (in US$; TV)	156.4						**0.163** (0.017)

Significant estimates are in bold.

Table 3
Repeatibility (R) and estimates of the permanent environmental effect (on diagonal) associated with six production traits in Peruvian alpacas and between-permanent environmental effects correlations (above diagonal).

	R	FD	CV	GFW	SL	SI	TV
Fibre diameter (in μm; FD)	0.578	**0.166** (0.013)	0.137 (0.044)	**0.623** (0.050)	0.279 (0.165)	**0.845** (0.185)	−0.181 (0.078)
Coefficient of variation of FD (in %; CV)	0.579		**0.259** (0.012)	**0.421** (0.052)	**0.545** (0.155)	**0.540** (0.220)	−**0.363** (0.083)
Greasy fleece weight (in kg; GFW)	0.316			**0.218** (0.019)	**0.916** (0.062)	0.520 (0.271)	**0.498** (0.058)
Staple length (in cm; SL)	0.090				**0.021** (0.006)	0.304 (0.285)	**0.750** (0.137)
Shearing interval (in days; SI)	0.069					**0.008** (0.004)	0.011 (0.378)
Textile value (in US$; TV)	0.299						**0.136** (0.024)

Standard errors of the estimates are in brackets. Significant estimates are in bold.

FD. Correlations between the c^2 for CV and the corresponding effects for GFW, SL and SI were positive and moderate to high ranging from 0.421 ± 0.052 for the pair CV-GFW to 0.545 ± 0.155 for the pair CV-SL, whilst the correlations between c^2 effects for the pair CV-TV was negative (−0.363 ± 0.083). Correlations estimated for the pairs FD-GFW and FD-SI were significant and high (0.623 ± 0.050 and 0.845 ± 0.185, respectively). The c^2 effects associated with GFW and SL seemed to be basically the same (estimated correlation of 0.916 ± 0.062). The higher correlations found for the c^2 effect associated with TV were with those associated with GFW (0.498 ± 0.058) and SL (0.750 ± 0.137).

4. Discussion

We carried out a genetic analysis in Peruvian alpacas for 4 relevant production traits (FD, CV, GFW and SL) and 2 additional traits (SI and TV) that are of particular interest for the selection program lead by PACOMARCA S.A. The mean values reported here for the analysed traits can be compared with others in the literature. Lupton et al. (2006) in US Huacayo alpacas reported average values of 27.85 μm for FD, 23.48% for CV and 11.6 cm for SL. Sumar (1991, cited by Frank et al., 2006) reported mean FD of 23.8 μm for Suri alpacas and 24.02 μm for Huacayo alpacas in the Peruvian Altiplano. Mean FD reported in Australian alpacas varied from 25.7 μm (Ponzoni et al., 1999) to 29.1 μm (McGregor and Butler, 2004) whilst in New Zealand alpacas ranged from 28.0 to 31.9 μm (Wuliji et al., 2000). Mean CV reported in Australian alpacas varied from 24.1% to 24.3% (Ponzoni et al., 1999; McGregor and Butler, 2004). In their review Frank et al. (2006) report average values for SL of 12.6 cm and 16.8 cm for Peruvian Huacayos and Suris, respectively, 9.9 cm in New Zealand alpacas and from 7.7 to 9.4 cm in Australian alpacas. Reports for mean GFW in New Zealand alpacas varied from 1.97 kg in weaned crias, to 3.02 kg in tuis between one and one and a half years old, with an intermediate value of 2.16 kg in adults (Wuliji et al., 2000) whilst those reported by McGregor (2002) in Australian alpacas varied from 2.09 to 3.01 kg.

There are no available references for estimates of genetic correlations between production traits in alpacas but also the number of estimates of heritability for these traits is scarce. In their review, Frank et al. (2006) reported estimates of heritability for GFW at first shearing varying from 0.21 to 0.35, for GFW at all ages varying from 0.63 to 0.69, for FD varying from 0.18 to 0.73, for SL at first shearing varying from 0.31 to 0.43 and for SL at all ages varying from 0.57 to 0.63. Our estimates would be in the lower limits of these ranges. However, Frank et al. (2006) pointed out that the higher estimates of heritability for the reported traits came from analyses carried out on New Zealand (Wuliji et al., 2000) or Australian alpacas (Ponzoni et al., 1999) thus concluding that heritabilities tended to be low to moderate in the high plateau environment and very high outside Altiplano conditions. The database analysed here has a correct structure thus making us confident of the results reported here. The low h^2 (and basically null c^2) estimated for SI is not surprising. In a similar manner as that reported for other traits in livestock (for example lactation length in dairy sheep; see Gutiérrez et al., 2007 as a review) that are highly affected by immediate management decisions, most factors affecting SI are of non-genetic origin. Since SI is considered by PACOMARCA S.A. as an economically important production trait further research should be done on the definition of gain rates able to characterise the desired economic goal: since the maintenance cost of the animals is the same, the shorter the in between-shearing interval is the higher the profits it creates.

No previous estimates on permanent environmental effects associated with production traits in alpacas are available. Heritabilities of GFW and SL are relatively low, those of FD and CV scored using precision instruments are somewhat higher. Reconsideration of recording practices for GFW and SL is recommended. The permanent environmental component was particularly noticeable for GFW which should be a warning that similar performance among shearings is not of genetic origin. The relationship among traits seems to be more important with a permanent environment than with genetics, and some of these traits are of particular interest. Therefore a higher TV should be expected when CV is reduced and this is true from a permanent environment point of view, but the opposite can be inferred from the genetic correlation warning that reducing CV via genetic selection will also carry a reduction in the TV. Fortunately this correlation, although significant, is low.

Given the scarce information on estimates of genetic parameters for production traits in alpaca it is advisable to contrast the present results with those obtained in other species with similar production goals such as sheep (Ponzoni et al., 1999). In their review of the literature, Safari et al. (2005) calculated a weighed average heritability in sheep specifically breeds for wool (mainly Merino) for GFW from 20 published papers of 0.37 ± 0.02, for FD from 33 published papers of 0.59 ± 0.02, for CV from 14 published papers of 0.52 ± 0.04 and for SL from 15 published papers of 0.46 ± 0.04. The same authors reported weighted mean genetic correlations and their 95% confidence interval (95% CI) among sheep wool traits for some of the traits analysed in alpacas. The mean genetic correlations for GFW-FD and GFW-SL computed by Safari et al. (2005) were positive, moderate (0.36 GFW-FD and 0.44 GFW-SL) and significant (95%CI: 0.07–0.59 GFW-FD and 0.00–0.74 GFW-SL). Those for FD-CV, FD-SL and CV-SL were low (−0.10, 0.19 and −0.06, respectively) and non-significant (95%CI: −0.32–0.14, −0.11–0.45 and −0.27–0.15, respectively). The scenario approached in the present study for the Peruvian alpacas coincide quite well with that summarised by Safari et al. (2005) for wool-specialised sheep breeds even though heritability estimates are lower. In any case, the lack of significant genetic correlation for FD-CV and for FD-GFW highlights the possibility of joint selection to reduce FD and CV.

Even though fibre diameter has traditionally been one of the most important economic selection objectives in specialised woolibre producing species, breeders pay a great deal of attention to objective indices of the economic value of an animal to be used as a selection criterion. Here we present the economic trait used in the PACOMARCA S.A. improvement program (TV) as the main selection criterion. The estimated parameters provided here make it possible to use FD rather than the TV index as selection criterion. The response to direct selection is $R = ih^2\sigma_p$ (Falconer and Mckay, 1996) where σ_p is the phenotypic variance and i the selection intensity. Substituting h^2 and σ_p for the corresponding estimates for TV, R = 2.039 i. The correlated response on a trait Y when using a different trait X as selection criterion is $CR_Y = ih_Xh_Yr_A\sigma_{pY}$, r_A

being the additive genetic correlation between traits, and, when considered both FD and TV, the response on TV would be 2.414 *i*. Therefore, it should be more efficient to use FD instead of TV as a selection criterion to increase textile value in Peruvian alpacas. Additionally, the use of FD would limit the costs of recording the additional information needed to compute TV.

Genetics of variability is an issue of increasing interest in animal breeding. Most recent approaches attempt genetic selection to reduce environmental variability around an optimum production level, the so called canalization (Gutiérrez et al., 2006). When many records per individual are available, the structure of data is better for addressing the variability in the models even when models have been developed to jointly fit the direct genetic effect of a trait and that associated with its variability (San-Cristobal et al., 1998). However, if a high number of records are available, genetic selection to modify the variability of a trait would be possible as long as a genetic variability of the standard deviation exists when it is analysed as a trait. Fortunately, since the selection objective is the within fleece sample variability rather than between animal variability, output from the OFDA analysing the fibre diameter provides a value of the standard deviation from a dense staple of fibre thus making it possible to treat the variability as another simple continuous trait without the methodological concerns related to canalisation. Usually a positive correlation exists between a trait and its variability as a consequence of a scale effect. Therefore, when the selection objective is to increase the mean value of a trait while decreasing its variability, it should be useful to find a measure of the variability independent of the mean value. Such a measure is the coefficient of variation of a trait but there can also be a genetic correlation between mean and environmental variability conducted to a canalized correlated response (Ibáñez-Escriche et al., 2008) when selecting to reduce the fibre diameter. Fortunately, this is not the case here given that such a correlation is near null with both traits being quite heritable.

5. Conclusions

In this study, variance components and genetic and permanent environmental parameters were estimated for six production traits in Peruvian alpacas as a contribution to ascertaining the performance of the species when exploited in Altiplano conditions. The between-traits patterns of genetic and environmental relationships assessed on the analysed traits suggest that FD should be the main selection criterion in improvement programs focused on increasing the profits of alpaca fibre producers. The FD has been shown to be superior to empirical indices constructed to increase textile value of the alpacas. The reported correlation matrices can be useful to implement a multitrait breeding value evaluation process for selection purposes.

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