Animal Reproduction Science 163 (2015) 48–55

Contents lists available at ScienceDirect

Animal Reproduction Science

journal homepage: www.elsevier.com/locate/anireprosci

Estimation of genetic parameters for reproductive traits in alpacas

A. Cruz[a], I. Cervantes[b], A. Burgos[a], R. Morante[a], J.P. Gutiérrez[b,*]

[a] *Fundo Pacomarca – INCA TOPS S.A., Miguel Forga 348, Arequipa, Perú*
[b] *Departamento de Producción Animal, Universidad Complutense de Madrid, Avda. Puerta de Hierro s/n, E-28040 Madrid, Spain*

ARTICLE INFO

Article history:
Received 21 June 2015
Received in revised form
28 September 2015
Accepted 29 September 2015
Available online 17 October 2015

Keywords:
Reproductive traits
Genetic parameters
Alpaca

ABSTRACT

One of the main deficiencies affecting animal breeding programs in Peruvian alpacas is the low reproductive performance leading to low number of animals available to select from, decreasing strongly the selection intensity. Some reproductive traits could be improved by artificial selection, but very few information about genetic parameters exists for these traits in this specie. The aim of this study was to estimate genetic parameters for six reproductive traits in alpacas both in Suri (SU) and Huacaya (HU) ecotypes, as well as their genetic relationship with fiber and morphological traits. Dataset belonging to Pacomarca experimental farm collected between 2000 and 2014 was used. Number of records for age at first service (AFS), age at first calving (AFC), copulation time (CT), pregnancy diagnosis (PD), gestation length (GL), and calving interval (CI) were, respectively, 1704, 854, 19,770, 5874, 4290 and 934. Pedigree consisted of 7742 animals. Regarding reproductive traits, model of analysis included additive and residual random effects for all traits, and also permanent environmental effect for CT, PD, GL and CI traits, with color and year of recording as fixed effects for all the reproductive traits and also age at mating and sex of calf for GL trait. Estimated heritabilities, respectively for HU and SU were 0.19 and 0.09 for AFS, 0.45 and 0.59 for AFC, 0.04 and 0.05 for CT, 0.07 and 0.05 for PD, 0.12 and 0.20 for GL, and 0.14 and 0.09 for CI. Genetic correlations between them ranged from −0.96 to 0.70. No important genetic correlations were found between reproductive traits and fiber or morphological traits in HU. However, some moderate favorable genetic correlations were found between reproductive and either fiber and morphological traits in SU. According to estimated genetic correlations, some reproductive traits might be included as additional selection criteria in HU.

1. Introduction

The alpaca (*Vicugna pacos*) is one of the four species of South American camelids. It lives in the Andes of South America mainly in Peru, above 3000 m over sea level. It has several productive skills (Quispe et al., 2009), but the main economic feature of this specie is the production of quality fiber.

One of the main deficiencies affecting animal breeding programs in Peruvian alpacas is the low reproductive performance (Bravo et al., 1997), leading to a very low number of animals to select from, decreasing strongly the selection intensity.

Reproductive performance can be increased by improving management, but can also be improved by artificial selection based in appropriate traits. However, information

* Corresponding author.
E-mail address: gutgar@vet.ucm.es (J.P. Gutiérrez).

http://dx.doi.org/10.1016/j.anireprosci.2015.09.017

about genetic parameters for reproductive traits is very scarce in alpacas. In this way, addressing indicators as measures of reproductive efficiency becomes an important issue in order to be included as additional selection objectives of breeding programs (Gutiérrez et al., 2002; Tonhati et al., 2000; Van der Westhuizen et al., 2000). Traits to be considered as potential selection criteria, might even have not only influence on fertility, but also a direct economic impact, as argued in beef cattle (Bourdon and Brinks, 1983; Rust and Groeneveld, 2001).

Reproductive profiling of alpacas has particular features. Mating is only carried out in summer months, in a period called campaign, and females not becoming pregnant in that period, will not offered to the male until next campaign. Under the usual management in alpacas, females are considered suitable to breed in the second campaign after being born. Age at first service (AFS) and age at first calving (AFC) can be therefore important reproductive performance traits to be dealt with, although AFS directly depends on management farmer decisions such as nutrition and animal management, the development state of young animals can condition this farmer decision and part of this development state can be under genetic control. AFC, instead, directly addresses the fertility of the female, combined with the information undergoing AFS. The information contained in AFC is equivalently measured through calving interval (CI) in adult females. Higher performance is attained if animals are younger at their first calving (lower AFC), and shorter is the CI. It has been shown in beef cattle that under this scenario of lower AFC and CI, cows produce more calves in their reproductive life (Philipsson, 1981; Taller, 1997; Rust and Groeneveld, 2001).

Induced ovulation is another particular reproductive feature of alpacas. The female is stimulated during the mating as a need for releasing luteinizing hormone by the anterior pituitary into the bloodstream (Fernández-Baca et al., 1970; Bravo et al., 1990). The copulation time, between 10 and 50 min (Fernández-Baca, 1993), could be determining the amount of stimulus. On the other hand, Adams and Ratto (2013) suggest that the hormones segregation inducing ovulation could also be due to biochemical recognition of the seminal plasma after mating. Therefore, copulation time (CT) could be used as an indirect indicator of probability of success, as this trait could be related to both the amount of stimulus on the female and the probability of semen release.

Fertility is the final target of economic value trait that needs to be improved. It could be early approached by carrying out pregnancy diagnosis (PD) by ultrasound, which has been concluded to be the best technique to be used in camelids (Alarcón et al., 1990; Aba, 2014) and other species (Kähn, 1992). An early application of the technique reduces the accuracy of the diagnostic, but helps to monitor the reproductive efficiency in females and mainly in males (Pearson et al., 2014; Ferrer, 2014). In addition, a late diagnosis will result in losses of time. Thus, Bravo et al. (1997) proposed the application between 15 and 30 days, although Parraguez et al. (1997) reported increased accuracy from 23 to 34 days in alpacas and llamas. As a compromise, it was decided to diagnose pregnancies 21 days after mating in this population. If pregnancy diagnosis results positive, then the female will give birth after a gestation length (GL) of about 11 months, with a high variation depending on the season (Davis et al., 1997; Rodriguez et al., 2014).

Several studies have been reported in Pacomarca experimental farm, in order to cumulate knowledge useful in a genetic improvement program (Gutiérrez et al., 2009, 2011, 2014; Cervantes et al., 2010; Pérez-Cabal et al., 2010; Paredes et al., 2014). In those, genetic parameters for several productive traits have been estimated, but nothing has been still done in the field of the reproduction genetics. The genetic relationship between reproductive and productive traits remains still also unknown. On the other hand, there is a tendency to include and increase the interest of reproductive traits in other species (Banks and Brown, 2009). However, these traits have not been planned to be used as selection objectives in alpacas to our knowledge.

The aim of this paper was to estimate the genetic parameters of some reproductive traits, as well as the genetic relationships among them and between them and other productive and morphological traits in alpacas, to evaluate their usefulness in breeding programs.

2. Material and methods

2.1. Data

Data used was obtained from PacoPro, the software used for management of information of Pacomarca experimental farm. This software integrates profuse information concerning all the activities leading to a better performance of alpacas. Pacomarca raises both ecotypes, Suri (SU) and Huacaya (HU), which are managed together except that breeding is only allowed within ecotype. Thus, two independent data sets have to be considered. Three subsets for each breed were obtained from the whole dataset:

(a) Reproductive traits: age at first service (AFS), age at first calving (AFC), copulation time (CT), pregnancy diagnosis at 21 days (PD), gestation length (GL) and calving interval (CI). PD was registered as a binary trait with 1 for negatives and 2 for positives.
(b) Fiber traits as described by Gutiérrez et al. (2009): fiber diameter (FD), standard deviation (SD), comfort factor (CF) and coefficient of variation (CV). These traits were computed from washed samples after minicored and 400 snippets of 2 mm using an Optical fiber Diameter Analyser (OFDA, IWTO-47-95).
(c) Morphological traits as described by Cervantes et al. (2010): density (DE), crimp (CR) in Huacaya ecotype or lock structure (LS) in Suri ecotype, head (HE), coverage (CO) and balance (BA).

Datasets 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 61 to 7407 days across traits.

A distribution of pedigree records by color, sex and ecotype is shown in Table 1. Both ecotypes were grouped by coat color in three classes, with similar representation:

Table 1
Number of pedigree records by color, sex and ecotype. HU, Huacaya; SU, Suri.

Coat color	Sex	HU	SU	Total	HU (%)	SU (%)
White	♂	1768	487	2255	29.0	29.4
	♀	2149	575	2724	35.4	34.6
Colors	♂	898	236	1134	14.8	14.5
	♀	924	283	1207	15.1	17.3
Black	♂	149	33	182	2.4	1.9
	♀	198	42	240	3.3	2.3
Total		6086	1656	7742	100.0	100.0

white (64%), colors (31%) and black (5%). The number of HU and SU animals in the pedigree was, respectively, 6086 and 1656 individuals. Number of records, mean and standard deviation of all the involved traits for HU and SU ecotypes are shown in Table 2. Concerning reproductive traits, the final total number of records available, respectively, for HU and SU ecotypes was 1369 and 334 for AFS, 679 and 175 for AFC, 15,736 and 4034 for both CT and PD, 4622 and 1252 for GL, and 3315 and 975 for CI. The number of records for fiber traits was 14,740 for HU and 4120 for SU. Records for morphological traits were 4501 in HU and 1216 in SU.

Seasonality was important in some of the reproductive analyzed traits. Distributions of IC records is shown in Fig. 1 for both SU and HU ecotypes as an example, but AFC and AFS had a similar pattern. However, distribution of the records for CT and GL became a continuous normal distribution (results not shown).

2.2. Methodology

Genetic parameters were estimated via a multitrait restricted maximum likelihood (REML) procedure applied to mixed linear models. Reproductive, morphological and fiber traits were analyzed together. Some traits were not Gaussian distributed. However, restricted maximum likelihood methodology has been shown to perform ideally in such circumstances (Goyache et al., 2003; Gutiérrez et al., 2007).

The model fitted for AFS, AFC, DE, CR, LS, HE, CO and BA was:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Zu} + \mathbf{e}$$

And the model fitted for CT, PD, GL, CI, FD, SD, CF and CV was:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Zu} + \mathbf{Wp} + \mathbf{e}$$

Table 2
Number of records, mean, standard deviation (sd) for all traits in Huacaya (HU) and Suri (SU) ecotypes.

Traits	Ecotype	Records	Mean	Standard deviation
Age first service (AFS)	HU	1369	754.5	168.6
	SU	334	745.8	168.2
Age fist calving (AFC)	HU	679	1177.0	221.0
	SU	175	1194.8	267.8
Copulation time (IT)	HU	15,736	19.5	7.8
	SU	4034	19.5	7.8
Pregnancy diagnosis (PD)	HU	15,736	1.30	0.5
	SU	4034	1.31	0.5
Gestation length (GL)	HU	4622	341.9	10.4
	SU	1252	342.8	10.0
Calving interval (CI)	HU	3315	470.1	213.1
	SU	975	463.7	220.6
Fiber diameter (FD)	HU	14,738	22.9	4.2
	SU	4122	24.9	5.0
Standard deviation (SD)	HU	14,738	5.4	1.1
	SU	4120	6.5	1.5
Comfort factor (CF)	HU	14,738	88.3	14.5
	SU	4122	79.9	19.8
Coefficient of variation (CV)	HU	14,735	23.7	3.7
	SU	4120	26.2	4.0
Density (DE)	HU	4501	3.3	0.7
	SU	1216	3.1	0.5
Crimp (CR)	HU	4501	2.8	0.9
Lock structure (LS)	SU	1216	2.9	0.7
Head (HE)	HU	4501	3.2	0.8
	SU	1216	2.9	0.6
Coverage (CO)	HU	4501	3.1	0.8
	SU	1216	3.1	0.7
Balance (BA)	HU	4499	3.1	0.5
	SU	1215	3.1	0.5

AFS and AFC in days, CT in minutes, PD value in range de 1 (empty) to 2 (pregnancy), GL and CI in days, FD and SD in microns, CF and CV in percent (%), DE, CR, LS, HE, CO and BA value in range 1–5.

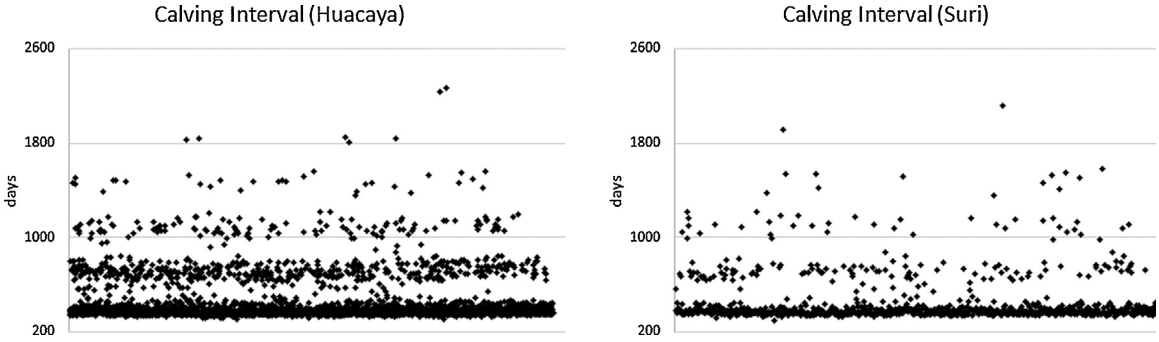

Fig. 1. Distribution of calving interval in Huacaya and Suri ecotypes.

$$\text{with} \begin{pmatrix} \mathbf{u} \\ \mathbf{p} \\ \mathbf{e} \end{pmatrix} \sim N\left(\begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix}, \begin{bmatrix} \mathbf{A} \otimes \mathbf{G_0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{I_p} \otimes \mathbf{P_0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{I_e} \otimes \mathbf{R_0} \end{bmatrix} \right)$$

where **y** is the vector of observations, **b** is the vector of fixed effects, **u** is the vector representing the additive genetic effects, **p** corresponds to the vector of permanent environments, and **e** is the vector of residuals; **X**, **Z** and **W** are the incidence matrices for respectively fixed, genetic and permanent effects, $\mathbf{I_e}$ 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, **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.

Regarding, the fixed effects included in the models for reproductive traits were: color (3 levels) and year of recording as contemporary group (14 levels) for all the reproductive traits and also age at mating as linear and quadratic covariate, and sex of calf (2 levels) for GL trait. The fixed effects for fiber traits were: color (3 levels), year of recording as contemporary group (14 levels), sex (2 levels) and age as linear and quadratic covariate. For the morphological traits the fixed effects were: color (3 levels), sex (2 levels) and year of recording as contemporary group (10 levels). HU and SU ecotypes were independently analyzed.

Genetic parameters were estimated using the VCE 6.0 program (Neumaier and Groeneveld, 1998).

3. Results

The heritabilities and repeatabilities obtained for the studied reproductive traits are first reported. Secondly, the genetic correlations between them are commented for both ecotypes. Subsequently the results obtained as regards genetic correlations with other production traits will be reported.

Estimates of heritabilities, repeatabilities and genetic correlations between all the involved traits are shown in Table 3 for HU and in Table 4 for SU. Standard errors of parameters were some higher in the SU ecotype because of a lower number of records but sufficiently low to provide reliable parameters.

Estimated heritabilities for reproductive traits were high for AFC in both ecotypes, 0.45 for HU and 0.59 for SU. For the rest of traits, they tended to be low, being, respectively, for HU and SU ecotypes, 0.19 and 0.09 for AFS, 0.12 and 0.20 for GL, and 0.14 and 0.09 for CI. Heritabilities were very low for CT, 0.04 for HU and 0.05 for SU ecotypes, and 0.07 and 0.05 for PD, respectively. Permanent environmental component was almost negligible in all reproductive traits.

The correlations between reproductive traits were in general favorable and ranged from −0.96 between PD and CI, to 0.70 between AFS and AFC in the HU ecotype. These figures were of −0.89 and 0.60 for the same pairs of traits in SU ecotype. CT was moderately genetically related with AFC, AFS and GL (−0.42, −0.29 and −0.37, respectively) in HU, while only had a similar relationship with GL (−0.34) in SU ecotype. Another two important favorable genetic correlations were also found between AFC and PD (−0.48 and −0.75 for, respectively, HU and SU ecotypes), and between AFC and CI (0.44 and 0.53 for, respectively, HU and SU ecotypes). Finally, there were two additional important correlations between reproductive traits in SU involving GL with PD (−0.40) and with CI (0.49).

Absolute genetic correlations estimated between reproductive traits and fiber traits, and between reproductive traits and morphological traits were all of them lower than 0.25 in HU ecotype and always lower than 0.35 in SU ecotype, and were in general favorable. To name some unfavorable, the correlation between AFS and DE was 0.24 in HU ecotype, and those between AFS with SD and CV were, respectively, −0.32 and −0.34 in SU ecotype. But, they were not of a big concern given their low magnitude.

4. Discussion

The estimated genetic parameters for six reproductive traits in an experimental population of HU and SU ecotypes of alpacas, allow to evaluate them as potential candidate traits to be included as criteria in breeding programs.

This is the first time that heritability of reproductive traits have been estimated in HU and SU ecotypes of alpacas as well as their genetic correlation with economical important traits as fiber and morphological traits are considered (Cervantes et al., 2010).

Table 3

Heritabilities (in diagonal), between traits genetic correlations (above diagonal), permanent environmental variances ratio (row c^2), repeatabilities (last row, *R*) and their corresponding standard errors (in brackets) for reproductive, productive and morphological traits in Huacaya ecotype. All heritabilities and genetic correlations higher than 0.20 in absolute value are in bold.

	AFS	AFC	CT	PD	GL	CI	FD
AFS	**0.19 (0.02)**	**0.70 (0.04)**	**−0.42 (0.05)**	0.14 (0.05)	0.12 (0.04)	−0.14 (0.05)	−0.11 (0.03)
AFC		**0.45 (0.04)**	**−0.29 (0.06)**	**−0.48 (0.03)**	0.09 (0.05)	**0.44 (0.04)**	0.03 (0.03)
CT			**0.04 (0.01)**	−0.18 (0.06)	**−0.37 (0.04)**	0.04 (0.05)	**0.22 (0.04)**
PD				**0.07 (0.01)**	−0.05 (0.03)	**−0.96 (0.01)**	−0.07 (0.02)
GL					**0.12 (0.01)**	0.11 (0.04)	−0.10 (0.03)
CI						**0.14 (0.01)**	0.17 (0.03)
FD							**0.32 (0.01)**
SD							
CF							
CV							
DE							
CR							
HE							
CO							
BA							
c^2			**0.06 (0.01)**	**0.00 (0.00)**	**0.10 (0.01)**	**0.00 (0.00)**	**0.15 (0.01)**
R			**0.10**	**0.07**	**0.22**	**0.14**	**0.47**

	SD	CF	CV	DE	CR	HE	CO	BA
AFS	−0.19 (0.04)	0.15 (0.04)	−0.18 (0.04)	**0.24 (0.05)**	0.19 (0.04)	0.05 (0.03)	0.11 (0.03)	0.10 (0.04)
AFC	−0.02 (0.03)	−0.06 (0.04)	−0.05 (0.03)	0.05 (0.05)	0.09 (0.03)	0.11 (0.03)	0.19 (0.02)	0.134 (0.04)
CT	0.16 (0.03)	**−0.22 (0.04)**	0.07 (0.03)	−0.13 (0.03)	−0.06 (0.02)	**−0.22 (0.04)**	0.05 (0.03)	−0.15 (0.04)
PD	−0.03 (0.02)	0.10 (0.02)	0.02 (0.02)	0.10 (0.03)	0.03 (0.02)	0.02 (0.02)	0.04 (0.02)	0.08 (0.03)
GL	−0.06 (0.02)	0.11 (0.03)	−0.03 (0.02)	0.08 (0.03)	−0.19 (0.03)	0.04 (0.04)	−0.08 (0.03)	0.07 (0.05)
CI	0.05 (0.02)	**−0.23 (0.03)**	−0.07 (0.03)	−0.12 (0.03)	−0.05 (0.03)	−0.01 (0.03)	−0.04 (0.03)	−0.09 (0.03)
FD	**0.70 (0.03)**	**−0.96 (0.02)**	0.21 (0.04)	−0.23 (0.03)	**−0.30 (0.03)**	−0.25 (0.03)	0.01 (0.03)	−0.21 (0.03)
SD	**0.40 (0.01)**	**−0.74 (0.02)**	**0.845 (0.03)**	**−0.35 (0.03)**	**−0.52 (0.02)**	−0.12 (0.02)	0.05 (0.03)	−0.14 (0.02)
CF		**0.22 (0.01)**	−0.32 (0.03)	0.22 (0.03)	**0.30 (0.03)**	0.20 (0.03)	−0.05 (0.03)	0.16 (0.04)
CV			**0.23 (0.01)**	**−0.32 (0.03)**	**−0.43 (0.02)**	0.02 (0.03)	0.08 (0.04)	−0.03 (0.02)
DE				**0.26 (0.01)**	**0.79 (0.04)**	0.24 (0.04)	−0.05 (0.04)	**0.29 (0.03)**
CR					**0.34 (0.01)**	**0.31 (0.03)**	0.14 (0.04)	**0.42 (0.03)**
HE						**0.37 (0.01)**	**0.70 (0.03)**	**0.94 (0.03)**
CO							**0.37 (0.01)**	**0.80 (0.02)**
BA								**0.21 (0.01)**
c^2	**0.15 (0.01)**	**0.17 (0.01)**	**0.09 (0.01)**					
R	**0.55**	**0.39**	**0.32**					

AFS, age at first service; AFC, age at first calving; CT, copulation time; PD, pregnancy diagnosis; GL, gestation length; CI, calving interval; FD, fiber diameter; SD, standard deviation; CF, comfort factor; CV, coefficient of variation; DE, density; CR, crimp; HE, head; CO, coverage; BA, balance.

This study has been carried out in order to explore the possibility of including reproductive performance as additional selection objective in a well-managed population of alpacas. These analyses have been carried out independently for both ecotypes, but, given that ecotypes differ in only a couple of genes (Presciuttini et al., 2010), estimates were expected to be close similar between them.

Heritabilities for fiber and morphological traits, along with the genetic correlations between these two sets of traits were not different from those estimated by Gutiérrez et al. (2014) with about 30% less number of records. These parameters will not be discussed here as they are not of particular concern in this paper.

Estimated heritability for AFS (0.19 in HU ecotype and 0.09 in SU) resulted similar than that obtained in other fiber producing animals such as Norwegian and Polish goats in which a heritability of 0.13 was reported (Bagnicka et al., 2007). Heritabilities for AFC (0.45 in HU ecotype and 0.59 in SU) were much higher than the values of 0.24 reported in Asturiana de los Valles (Gutiérrez et al., 2002) and 0.22 in Asturiana de la Montaña (Baro et al., 2012), also higher than those estimated in dairy buffaloes in Brazil (0.16, Barros et al., 2013) and in Iran (0.14, Hasanpur et al., 2011), in several goat breeds in herds of United States (0.23, García-Peniche et al., 2012) and in Brown Swiss cattle (0.02, Tiezzi et al., 2012). Values were similar to those found in Mexican Brahman cattle (0.46, Estrada-León et al., 2008).

Even though the estimated heritabilities of GL in HU and SU ecotypes were not too low, other authors attained higher values. Cervantes et al. (2010) reported a value of 0.33 ± 0.03 in Asturiana de los Valles and Chud et al. (2014) estimated a heritability of 0.38 ± 0.03 in Nellore beef cattle for this trait.

Concerning CI, the heritabilities found in HU and SU ecotypes were in the range reported in the literature, a value of 0.10 in the Asturiana de la Montaña (Baro et al., 2012), 0.13 in Asturiana de los Valles (Gutiérrez et al., 2002), 0.05 and 0.34 in dairy buffaloes, respectively, in Brazil and Iran (Barros et al., 2013; Hasanpur et al., 2011), 0.15 in Mexican Brahman cattle (Estrada-León et al., 2008), 0.02 and 0.03 in Polish and Norwegian (Bagnicka et al., 2007), and 0.05 in dairy goats (García-Peniche et al., 2012).

This analysis has been performed in order to check the possibility of including some reproductive trait as a

Table 4
Heritabilities (in diagonal), between traits genetic correlations (above diagonal), permanent environmental variances ratio (row c^2), repeatabilities (last row, R) and their corresponding standard errors (in brackets) for reproductive, productive and morphological traits in Suri ecotype. All heritabilities and genetic correlations higher than 0.20 in absolute value are in bold.

	AFS	AFC	CT	PD	GL	CI	FD
AFS	**0.09 (0.02)**	**0.60 (0.03)**	0.22 (0.07)	−0.24 (0.09)	−**0.31 (0.06)**	0.20 (0.06)	−0.18 (0.03)
AFC		**0.59 (0.04)**	−0.05 (0.08)	−**0.75 (0.07)**	−0.10 (0.07)	**0.53 (0.07)**	0.06 (0.05)
CT			**0.05 (0.01)**	0.16 (0.08)	−**0.34 (0.05)**	0.06 (0.07)	0.19 (0.05)
PD				**0.05 (0.08)**	−**0.40 (0.07)**	−**0.89 (0.04)**	0.04 (0.05)
GL					**0.20 (0.02)**	**0.49 (0.07)**	−0.14 (0.04)
CI						**0.09 (0.01)**	0.11 (0.05)
FD							**0.50 (0.02)**
SD							
CF							
CV							
DE							
LS							
HE							
CO							
BA							
c^2			**0.04 (0.01)**	**0.00 (0.00)**	**0.02 (0.01)**	**0.02 (0.00)**	**0.08 (0.01)**
R			**0.09**	**0.05**	**0.22**	**0.11**	**0.58**

	SD	CF	CV	DE	LS	HE	CO	BA
AFS	−**0.32 (0.03)**	0.17 (0.04)	−**0.34 (0.05)**	0.14 (0.06)	−0.10 (0.05)	0.09 (0.04)	−0.18 (0.05)	0.03 (0.03)
AFC	0.11 (0.04)	−0.02 (0.05)	0.06 (0.04)	−0.10 (0.09)	−0.01 (0.09)	−**0.25 (0.06)**	−**0.27 (0.05)**	−**0.29 (0.06)**
CT	**0.20 (0.04)**	−0.23 (0.05)	0.15 (0.04)	−0.03 (0.05)	−**0.30 (0.05)**	−0.06 (0.05)	0.02 (0.04)	0.06 (0.04)
PD	−0.16 (0.05)	−0.04 (0.05)	−**0.25 (0.06)**	0.07 (0.07)	−0.14 (0.05)	0.13 (0.05)	0.15 (0.04)	0.18 (0.06)
GL	−0.05 (0.04)	0.15 (0.04)	0.04 (0.04)	**0.22 (0.04)**	0.09 (0.05)	−0.04 (0.06)	−0.04 (0.05)	−0.19 (0.06)
CI	0.17 (0.05)	−0.15 (0.04)	0.18 (0.06)	0.07 (0.06)	0.04 (0.05)	−0.12 (0.05)	−0.07 (0.05)	−0.15 (0.07)
FD	**0.78 (0.04)**	−**0.98 (0.01)**	**0.27 (0.06)**	0.19 (0.04)	−0.22 (0.04)	−0.09 (0.06)	0.13 (0.03)	−0.09 (0.05)
SD	**0.50 (0.02)**	−**0.80 (0.03)**	**0.81 (0.02)**	0.09 (0.05)	−0.25 (0.04)	−0.08 (0.03)	0.10 (0.03)	−0.10 (0.03)
CF		**0.37 (0.02)**	−**0.34 (0.05)**	−0.22 (0.04)	**0.27 (0.04)**	0.08 (0.05)	−0.15 (0.03)	0.08 (0.05)
CV			**0.26 (0.01)**	−0.03 (0.05)	−0.19 (0.04)	−0.01 (0.04)	0.04 (0.04)	−0.04 (0.03)
DE				**0.16 (0.02)**	**0.36 (0.06)**	**0.72 (0.04)**	**0.68 (0.04)**	**0.57 (0.05)**
LS					**0.20 (0.02)**	**0.62 (0.04)**	**0.35 (0.04)**	**0.71 (0.04)**
HE						**0.25 (0.02)**	**0.78 (0.04)**	**0.95 (0.02)**
CO							**0.26 (0.03)**	**0.72 (0.04)**
BA								**0.22 (0.02)**
c^2	**0.12 (0.01)**	**0.14 (0.01)**	**0.10 (0.01)**					
R	**0.62**	**0.51**	**0.36**					

AFS, age at first service; AFC, age at first calving; CT, copulation time; PD, pregnancy diagnosis; GL, gestation length; CI, calving interval; FD, fiber diameter; SD, standard deviation; CF, comfort factor; CV, coefficient of variation; DE, density; LS, lock structure; HE, head; CO, coverage; BA, balance.

selection objective in alpaca breeding programs. Looking at the estimated heritabilities for reproductive traits, their values suggest discarding CT and PD as possible artificial selection criterion because of their extremely low value. On one hand, PD would theoretically be one of the most important reproductive traits as directly addresses the success of the mating. However, it is a binary trait which leads also to a low heritability value (Altarriba et al., 1998). On the contrary, AFC or CI had a higher estimated heritability and an important genetic correlation with PD. In this sense, even though heritability for AFC was much higher than CI heritability, this last trait had the highest genetic correlation with PD. Another advantage of using CI instead of AFC is that CI is a trait affecting all the reproductive life of the female, while AFC only affects to the elapsed time from being born to the first calving. Anyway, what seems clear is the low usefulness of PD as selection criterion. Regarding CT, it does not seem a potentially interesting trait in breeding programs, but it has been included here in order to assess its possible influence on fertility, as well as the influence of younger animals in the CT as measured by its genetic correlation with AFS and AFC. As the genetic correlation between CT and PD was very low, CT does not seem a good indicator of fertility and can be ignored as a useful trait in reproductive management. The only interesting genetic correlation found involving CT, was that with AFS in HU, showing that in this ecotype, younger animals need further time for copulation.

AFS must be also discarded as a selection objective. First, it has an important management component since it is the farmer who decides the time the animal need to be used for mating. Only part of this decision seems to be dependent on the genetic background of the animal. On the other hand, AFC has an important genetic correlation with AFS in both ecotypes with a much higher heritability. Summarizing, animals with a shorter AFC will have a higher rate of pregnancy (genetic correlation of −0.48 with PD in HU and −0.75 in SU), and will spend a shorter open days period (genetic correlation of 0.44 with CI in HU and 0.53 in SU). Moreover, the heritability of this trait is by far the highest among the reproductive traits. It is also interesting to note that AFC is strongly conditioned by the seasonality of the reproduction in alpacas. Therefore, reducing AFC trait several weeks could result in reducing 1 year the beginning of reproductive age, with the consequent strong benefit for the farmers. Something similar could happen with CI trait. Again, considering also CI as a valuable trait and economically important trait to select would also be sensible, it has not too low heritability (0.14 in HU and 0.09 in SU), it has the highest genetic correlation with PD (−0.96 in HU and −0.89 in SU), and a medium genetic correlation with AFC. Moreover, in SU it has also a favorable genetic correlation with GL (0.49), another trait contributing to modulate the days open. Shortening CI would lead to females being pregnant under fewer attempts and males could also mate a higher number of females. In addition, easiness to becoming pregnant would increase the number of births at the starting of the campaign, when the pasture has higher quality favoring the milk production of the mothers and lowering the risk of respiratory diseases which are more frequent starting the winter.

Another point to discuss is the genetic relationship that reproductive traits would have with fiber and morphological traits. Fortunately, those relationships were never importantly unfavorable. On the other hand, these relationships were not general across ecotypes and could be due only to genetic associations not based in a real genetic background. In HU, looking at the genetic correlations higher than 0.20 in absolute value, only a small unfavorable genetic correlation (0.24) appeared between AFS and DE, but AFS has been discarded above as a potential selection objective. Regarding favorable genetic correlations, only CI had a small value of −0.23 with CF, suggesting that animals with shorter CI will tend to have a slightly better CF of the fiber. Nevertheless, in SU ecotype, the reproductive trait most related with morphology was AFC. Thus animals calving younger will tend to have better HE (−0.25), CO (−0.27) and BA (−0.29). Regarding fiber traits, AFS had an unfavorable genetic correlation with SD (−0.32) and CV (−0.34), the traits measuring the variability of the fiber. However, as AFC had null genetic correlation with these traits, it seems that the management decision of mating the animal is based on some appearance of the fleece that the farmer identified as maturity of the animals. On the other hand, as previously discussed, AFS was also discarded as a potential selection criterion.

Summarizing, heritabilities and genetic correlations among reproductive traits were very similar across ecotypes. Only AFC and CI would be useful in breeding programs because they had consistent heritabilities, bringing about a desired correlated positive response in pregnancy. Genetic correlations of these traits with other economically important fiber and morphological traits were not important in both ecotypes.

5. Conclusion

In this study the genetic parameters for six reproductive traits were estimated in HU and SU ecotypes of alpacas, in order to evaluate them as potential candidate traits to be included as criteria in breeding programs. A detailed inspection of the estimated genetic parameters led to the conclusion that only AFC and CI traits would be useful in such breeding programs. The high heritability of AFC would ensure a quick genetic response resulting in higher selection intensity, and consequently increasing the genetic response to selection in productive traits. The availability of higher number of animals born would also bring about more income to the farmer when selling or slaughtering animals. Despite its smaller heritability, also CI would be advised to be included among the selection criteria. The success in the selection response for this trait would have repercussion in each of the pregnancies of each animal, and fertility would increase as shown by the important genetic correlation it has with diagnosed pregnancies.

A selection index including AFC and/or CI as selection criteria would be advised in HU, but first studying the appropriate weights ensuring the desired genetic proportional response (Gutiérrez et al., 2014). It might also be done in SU, but in this case, the favorable genetic correlations found ensure that these traits are being indirectly selected in this ecotype.

Conflicts of interest

None.

References

Aba, M., 2014. Anatomy and physiology of reproduction in the female llama and alpaca. In: Llama and Alpaca Care. Elsevier, St Louis, pp. 140–150 (Chapter 14).
Adams, G., Ratto, M., 2013. Ovulation-inducing factor in seminal plasma: a review. Anim. Reprod. Sci. 136, 148–156.
Alarcón, V., Sumar, J., Riera, G., Foote, W., 1990. Comparison of three methods of pregnancy diagnosis in alpacas and llamas. Theriogenology 34, 1119–1127.
Altarriba, J.L., Varona, L.A., García-Cortés, A., Moreno, C., 1998. Bayesian inference of variance components for litter size in Rasa Aragonesa sheep. J. Anim. Sci. 76, 23–28.
Bagnicka, E., Wallin, E., Łukaszewicz, M., Ådnøy, T., 2007. Heritability for reproduction traits in Polish and Norwegian populations of dairy goats. Small Rumin. Res. 68, 256–262.
Banks, R.G., Brown, D.J., 2009. Genetic improvement in the Australasian Merino – management of a diverse gene pool for changing markets. Anim. Genet. Resour. Inf. 45, 29–36.
Baro, J.A., Carleos, C., Menendez-Buxadera, A., Rodriguez-Castañon, A., Cañon, J., 2012. Genetic variability underlying maternal traits of Asturiana de la Montaña beef cattle. Span. J. Agric. Res. 10, 69–73.
Barros, C., da, C., Aspilcueta-Borquis, R.R., Tonhati, H., Fraga, A.B., 2013. Genetic parameters for productive and reproductive traits for milk buffalo in Brazil. Buffalo Bull. 32, 688–691.
Bourdon, R.M., Brinks, J.S., 1983. Genetic environmental and phenotypic relationships among gestation length, birth weight, growth traits and age at first calving in beef cattle. J. Anim. Sci. 55, 543–553.
Bravo, W.P., Fowler, M.R., Stabenfeldt, B.H., Lasley, B.L., 1990. Endocrine responses in the llama to copulation. Theriogenology 33, 691–699.
Bravo, P.W., Solis, P., Ordóñez, C., Alarcón, V., 1997. Fertility of the male alpaca: effect of daily consecutive breeding. Anim. Reprod. Sci. 46, 305–312.
Cervantes, I., Pérez-Cabal, M.A., Morante, R., Burgos, A., Salgado, C., Nieto, B., Goyache, F., Gutiérrez, J.P., 2010. Genetic parameters and relationships between fibre and type traits in two breeds of Peruvian alpacas. Small Rumin. Res. 88, 6–11.
Chud, T., Caetano, S., Buzanskas, M., Grossi, D., Guidolin, D., Nascimento, G., Rosa, J., Loboe, R., Munari, D., 2014. Genetic analysis for gestation length, birth weight, weaning weight, and accumulated productivity in Nellore beef cattle. Livest. Sci. 170, 16–21.
Davis, G., Dodds, K., Moore, G., Bruce, G., 1997. Seasonal effects on gestation length and birth weight in alpacas. Anim. Reprod. Sci. 46, 297–303.
Estrada-León, R.J., Magaña, J.G., Segura-Correa, J.C., 2008. Parámetros genéticos para caracteres reproductivos de vacas Brahman en un hato del sureste de México. Trop. Subtrop. Agroecosyst. 8, 259–263.
Fernández-Baca, S., 1993. Manipulation of reproductive functions in male and female new world camelids. Anim. Reprod. Sci. 33, 307–323.

Fernández-Baca, S., Madden, D.H.L., Novoa, C., 1970. Effects of different mating stimuli on induction of ovulation in the alpaca. J. Reprod. Fertil. 22, 261–267.
Ferrer, M.S., 2014. Diagnosis of pregnancy and evaluation of high-risk pregnancy. In: Llama and Alpaca Care. Elsevier, St Louis, pp. 250–256 (Chapter 22).
García-Peniche, T.B., Montaldo, H.H., Valencia-Posadas, M., Wiggans, G.R., Hubbard, S.M., Torres-Vasquez, J.A., Shepard, L., 2012. Breed differences over time and heritability estimates for production and reproduction traits of dairy goats in the United States. J. Dairy Sci. 95, 2707–2717.
Goyache, F., Gutiérrez, J.P., Álvarez, I., Fernández, I., Royo, L.J., Gomez, E., 2003. Genetic analysis of calf survival at different preweaning ages in beef cattle. Livest. Prod. Sci. 83, 13–20.
Gutiérrez, J.P., Alvarez, I., Fernandez, I., Royo, L.J., Diez, J., Goyache, F., 2002. Genetic relationships between calving date, calving interval, age at first calving and type traits in beef cattle. Livest. Prod. Sci. 78, 215–222.
Gutiérrez, J.P., Goyache, F., Fernández, I., Álvarez, I., Royo, L.J., 2007. Genetic relationships among calving ease, calving interval, birth weight and weaning weight in the Asturiana de los Valles beef cattle breed. J. Anim. Sci. 85, 69–75.
Gutiérrez, J.P., Goyache, F., Burgos, A., Cervantes, I., 2009. Genetic analysis of six production traits in Peruvian alpacas. Livest. Sci. 123, 193–197.
Gutiérrez, J.P., Varona, L., Pun, A., Morante, R., Burgos, A., Cervantes, I., Pérez-Cabal, M.A., 2011. Genetic parameters for growth of fiber diameter in alpacas. J. Anim. Sci. 89, 2310–2315.
Gutiérrez, J.P., Cervantes, I., Pérez-Cabal, M.A., Burgos, A., Morante, R., 2014. Weighting fibre and morphological traits in a genetic index for an alpaca breeding program. Animal 8 (3), 360–369.
Hasanpur, K., Shahrbabak, M.M., Sadeghi, M., Kiyanzad, D., 2011. Estimation of environmental factors effects and genetic parameters of some reproductive traits of Iranian buffaloes. In: SAADC, vol. III, pp. 787–792.
Kähn, W., 1992. Ultrasonography as a diagnostic tool in female animal reproduction. Anim. Reprod. Sci. 28, 1–10.
Neumaier, A., Groeneveld, E., 1998. Restricted maximum likelihood estimation of covariances in sparse linear models. Genet. Sel. Evol. 30, 3–26.
Paredes, M.M., Membrillo, A., Gutiérrez, J.P., Cervantes, I., Azor, P.J., Morante, R., Alonso-Moraga, A., Molina, A., Muñoz-Serrano, A., 2014. Association of microsatellite markers with fiber diameter trait in Peruvian alpacas (*Vicugna pacos*). Livest. Sci. 161, 6–16.
Parraguez, V., Cortéz, S., Gazitúa, F., Ferrando, G., MacNiven, V., Raggi, L., 1997. Early pregnancy diagnosis in alpaca (*Lama pacos*) and llama (*Lama glama*) by ultrasound. Anim. Reprod. Sci. 47, 113–121.
Pearson, L.K., Rodriguez, J.S., Tibary, A., 2014. Breeding management. In: Llama and Alpaca Care. Elsevier, St Louis, pp. 162–168 (Chapter 16).
Pérez-Cabal, M.A., Cervantes, I., Morante, R., Burgos, A., Goyache, F., Gutierrez, J.P., 2010. Analysis of the existence of major genes affecting alpaca fiber traits. J. Anim. Sci. 88, 3783–3788.
Philipsson, J., 1981. Genetic aspects of female fertility in dairy cattle. Livest. Prod. Sci. 8, 307–319.
Presciuttini, S., Valbonesi, A., Apaza, N., Antonini, M., Huanca, T., Renieri, C., 2010. Fleece variation in alpaca (*Vicugna pacos*): a two-locus model for the Suri/Huacaya phenotype. BMC Genet. 11, 70–77.
Quispe, E.C., Rodriguez, T.C., Iñiguez, L.R., Mueller, J.P., 2009. Producción de fibra de alpaca, llama, vicuña, y guanaco en Sudamérica. Anim. Genet. Resour. Inf. 45, 1–14.
Rodriguez, J.S., Pearson, L.K., Tibary, A., 2014. Parturition and obstetrics. In: Llama and Alpaca Care. Elsevier, St Louis, pp. 274–286 (Chapter 24).
Rust, T., Groeneveld, E., 2001. Variance component estimation on female fertility traits in beef cattle. S. Afr. J. Anim. Sci. 31, 131–141.
Taller, G., 1997. Genetic and breeding for fertility. In: Proceedings of International Workshop on Genetic Improvement of Functional Traits in Cattle; Fertility and Reproduction, Grub, Germany, November 23–25. Bulletin 18, pp. 55–61.
Tiezzi, F., Maltecca, C., Cecchinato, A., Penasa, M., Bittante, G., 2012. Genetic parameters for fertility of dairy heifers and cows at different parities and relationships with production traits in first lactation. J. Dairy Sci. 95, 7355–7362.
Tonhati, H., Vascocellos, F.B., Alburquerque, L.G., 2000. Genetic aspects of productive and reproductive traits in a murrah buffalo herd in Sao Paulo, Brazil. J. Anim. Breed. Genet. 117, 331–339.
Van der Westhuizen, R.R., Schoeman, S.J., Jordaan, G.F., Van Wyck, J.B., 2000. Heritabilities of reproductive traits in a beef cattle herd using a multitraits analysis. S. Afr. J. Anim. Sci. 30 (Suppl. 1), 140–141.