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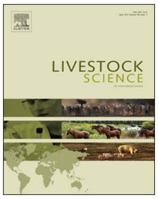

Effect of the gestation and lactation on fiber diameter and its variability in Peruvian alpacas

Alan Cruz[a], Renzo Morante[a], Isabel Cervantes[b], Alonso Burgos[a], Juan Pablo Gutiérrez[b,*]

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

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ABSTRACT

A study was conducted to know the influence of the pregnancy and lactation states on the fiber performance in alpacas at Pacomarca experimental farm in the Peruvian highlands. Records obtained from the regular performance recording software of the farm were used, gathering 8648 records of 1541 females and 366 males of Huacaya ecotype, and 2410 records of 374 females and 132 males of Suri ecotype, registered from 2001 to 2015 and belonging to animals of three or more years. A mixed linear model for fiber diameter, standard deviation and coefficient of variation fitted the physiological state with five categories (milking, pregnant, milking and pregnant, open females and males) as an effect jointly with others such as year of recording, age from 3 to 9 or more years old and coat color. Huacaya and Suri ecotypes were independently analyzed. All the effects included in the model appeared as highly significant, being the paired differences less significant in Suri because of the lower number of records. Lactation physiological state appeared as an important effect affecting fiber performance, explaining a difference of 1.2 and 1.0 µm of differences in respectively Huacaya and Suri pregnant females, while pregnancy appeared with a much less relevant influence. Other factors greatly influenced the fiber diameter. Thus, age had a very important effect increasing 3.71 µm from 3 to 9 years of age in huacaya and 4.52 µm en Suri. A difference of 3.09 µm in huacaya and 5.93 µm in Suri was found between dark and white coat colored alpacas. These results recommend modifying the genetic evaluation model by fitting the physiological state of females to increase the accuracy of the breeding values used to select animals in the breeding scheme of the farm.

1. Introduction

International market of natural fibers based on natural fiber is highly competitive for the textile industry. Pacomarca experimental farm was created to face this, developing a successful breeding program while addressing profuse research (Gutiérrez et al., 2009, 2011, 2014, Cervantes et al., 2010, Pérez-Cabal et al., 2010, Paredes et al., 2014, Cruz et al., 2015, 2016). The main objective selection in alpacas is the reduction in fiber diameter to produce fine fiber. Genetic improvement should also be encompassed with improvement in other areas such as nutrition, health, reproduction and management as part of an integrated business management strategy (McGregor et al., 2013a, 2013b, 2016). The estimated heritabilities for fiber traits in alpacas have been moderate to high, so the responses to artificial selection have been relevant for these traits (Gutiérrez et al., 2009, 2014; Cruz et al., 2015). Efficient selection has to be based in top-rated animals according to reliable breeding values for the desired traits, and the reliabilities depend on the amount of information provided by both each individual and its parents. In addition the fitted model for evaluation of the animals would have to include all effects that have influence on the traits (Gutiérrez, 2010). The current statistical model used for genetic evaluation in Pacomarca experimental farm includes, among other effects, the sex, although this has not ever seemed to be highly relevant in the fiber diameter and its variability. However, across their life, the females undergo significant changes in weight, body condition, feeding habits and feed requirements according to pregnancy and lactation periods.

The female alpaca starts reproduction at two years of age, reaching three years usually with a younger animal on its care. From this age onwards a female can be clearly identified under periods of gestation and lactation. A female becoming pregnant has usually a gestation of about 342 days of length, not coming back open until the next breeding season. After calving, the baby will suckle about five or six months (Cruz et al., 2015), representing an overlapping of gestation and lactation in which the female mobilizes the nutrient reserves according to their physiological needs, which may affect fiber performance (low

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[*] Corresponding author.
E-mail addresses: alancruzc@outlook.com (A. Cruz), gutgar@vet.ucm.es (J.P. Gutiérrez).

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Table 1
Distribution of fiber records according to the status of the animal in both Huacaya and Suri ecotypes.

	Huacaya ecotype						**Suri ecotype**					
Years of age	**O**	**M**	**P**	**PM**	**S**	**Total**	**O**	**M**	**P**	**PM**	**S**	**Total**
3	5	4	15	7	28	**59**	2	2	3	1	8	**16**
4	237	134	217	455	341	**1384**	47	35	69	125	96	**372**
5	316	184	152	419	164	**1235**	32	52	49	126	57	**316**
6	228	176	160	399	116	**1079**	35	46	61	136	45	**323**
7	149	144	195	370	82	**940**	32	44	55	129	34	**294**
8	119	118	179	375	53	**844**	31	28	37	125	20	**241**
9 or more	405	604	626	1342	130	**3107**	133	154	166	335	60	**848**
Total	1459	1364	1544	3367	914	**8648**	312	361	440	977	320	**2410**

(O): open; (P): pregnant; (M): milking; (PM): pregnant and milking; (S): sires.

fiber diameter and variability). Then, two very different stages can be defined within pregnancy period. The starting half of the gestation period with increase in the levels of anabolic hormones, and a consequent increase of blood volume, increase in the cardiac output in turn, also an increase in the nutrient reserves, fat and liver glycogen and appetite, and also increasing the food intake. The rest of the pregnancy carries an increase in catabolic hormones, leading to the mobilization of fat reserves and nutrients, decreasing the hepatic glycogen and increasing the metabolism, even in the absence of food intake. Similarly to pregnancy, the energy expenditure is sensitively increased during lactation, resulting in mobilization of energetic reserves to turn them into components of milk. Liesegang et al. (2006) reported mobilizations of the total bone mineral content occur at the end of gestation and beginnings of lactation in goats and sheep.

Metabolic adaptation has been found important for fiber production during pregnancy in sheep when raised in intensive system (Duehlmeier et al., 2011). Likewise the nutrition influences the milk production and the formation of fetal exoskeleton during the gestation, increasing metabolic mobilization of some components, especially the calcium (Liesegang et al., 2007). Also animals under gestation and lactation are more susceptible to diseases, especially parasites that were detrimental in milk production and production of fiber (González-Garduño et al., 2014). Nutritional effects on alpacas and merino sheep have also been reported on fiber yields (McGregor, 2002) and goats (McGregor et al., 2013a, 2013b).

Routine annual estimation of genetic parameters and breeding values prediction are currently being carried out independently for the two defined ecotypes in Pacomarca. The model used to perform such analyses includes the month-year of sampling, the coat color with three levels (white, light fawn and dark) and the age (linear and quadratic covariate) as effects (Cervantes et al., 2010; Cruz et al., 2015, 2016; Gutiérrez et al., 2009, 2011). However, physiological status of the female concerning gestation and lactation can importantly influence on the fiber features, and could be interesting to take part of the model. Quantifying gestation and lactation influence seems to be needed. Thus, this research aimed to study the effect of gestation and lactation on fiber diameter, standard deviations and coefficient of variation of the fiber diameter to evaluate their inclusion in the models used for the prediction of breeding values. As a secondary objective, influence of color, year and age on fiber diameter and its variability was also addressed.

2. Material and methods

The data were collected between 2001 and 2015, in the Pacomarca experimental farm, and correspond to 1907 (1541 females and 366 males) Huacaya ecotype individuals and 506 (374 females and 132 males) Suri ecotype animals, three or more years old. Alpaca females are suitable for reproduction at two years of age, but they only can become lactating or sufficiently advanced pregnant from three years old. Therefore, animals younger than three years were ignored in these analyses because they are much finer and has no chance of having pregnancies and milking stages. The mean age was 6.9 years for both Huacaya and Suri ecotypes. Animals with records of fiber performance were classified according to the state of the animal. For the Huacaya ecotype the number of records owned by open females not milking an offspring (O) was 1459, there were 1364 records for open females milking an offspring (M), 1544 records for pregnant females no milking an offspring (P), 3367 pregnant females simultaneously milking an offspring (PM), and 914 males (S). The respective records for the Suri ecotype were 312, 361, 440, 977 and 320. This classification was considered as the target group for this research in order to assess the influence of the physiological state on fiber performance. As a by-product of the analyses, significance was also studied concerning other highly relevant effects analyzed simultaneously, such as year, color and age effects. Description of the data structure according to the main grouping and the age in years is shown in Table 1. Concerning performance traits, the fiber samples were shorn from the middle side of the body. These samples were washed and after minicored and 4000 snippets of 2 mm using an Optical Fiber Diameter Analyzer 100 in the laboratory of Inca Tops S.A. (IWTO-47-95, 1995). The analyzed traits were the Fiber Diameter (FD), the Standard Deviation (SD), both FD and SD measured in μm and Coefficient of Variation (CV) expressed in percentage (%).

The three traits were analyzed under a linear model fitting the physiological state group as an effect, but also the age in years from three to nine or more, the coat color defined in white, cream and dark groups, and the year of recording from 2001 to 2015 were fitted to take into account the same effects fitted in the genetic evaluation routine process (Cervantes et al., 2010; Gutiérrez et al., 2014). This enabled establishing conclusions about the need of including milking and pregnancy states in that routine genetic evaluation process. Depending on the number of records, some first order interactions between effects were estimable and also fitted. These interactions were: physiological state by age, physiological state by coat color and age by coat color in Huacaya. Lactation and gestation influence did not appear as significant in the Suri ecotype when the interactions were fitted, probably due to a low number of records for such a complex model. Because of that, they were not fitted in the Suri ecotype. Conclusions have to be taken with caution in this ecotype. Finally, also the individual was fitted in the model as a random effect given that there were repeated measures for several animals. Analyses were carried out using the PROC MIXED of SAS software (1999). Differences between the main five groups were estimated also using the same procedure, establishing significant differences between groups based on the least significant difference (LSD) methodology.

3. Results

Table 2 shows the significance of the different effects fitted in the

Table 2
Significance of the effects influencing fiber performance in Huacaya and Suri ecotypes.

		Huacaya			Suri		
Effect	Degrees of freedom	FD	SD	CV	FD	SD	CV
Physiological state	4	***	***	***	***	***	NS
Age	6	***	***	***	***	***	NS
Color	2	***	***	***	***	***	NS
Year	14	***	***	***	***	***	***
P. State*Age	24	***	***	***	–	–	–
P. State*Color	8	*	NS	***	–	–	–
Age*Color	12	NS	***	***	–	–	–
Repeatability	–	0.58	0.61	0.46	0.66	0.64	0.45

(FD): fiber diameter; (SD): standard deviation; (CV): coefficient of variation; (NS): non-significant; (*): $p < 0.05$; (***): $p < 0.001$.

model on fiber traits, as well as the estimated repeatabilities of the traits for both Huacaya and Suri ecotypes. All main effects were highly significant except for CV in Suri ecotype in which only the year effect become significant. Physiological state by age interaction was always significant, but interactions involving coat color were not always significant. Repeatabilities were between 0.45 and 0.66 being particularly lower in CV.

Table 3 shows the least squared means for the five physiological state groups in both ecotypes and the significant differences found between the groups. These significant differences were always greater for Huacaya than for Suri ecotype, because of the fourfold number of records in the first one. For the Huacaya ecotype, the females under milking stage (PM and M) were significantly the finest (24.46 ± 0.19 µm and 24.51 ± 0.24 µm respectively), with the sires being the coarsest (26.58 ± 0.28 µm), and having the open (25.16 ± 0.25) and pregnant females (with 25.67 ± 0.19) an intermediate fineness without significant difference between them. For the Suri ecotype PM females, with 27.15 ± 0.30 µm and M females, with 27.45 ± 0.31 µm were also found to be significantly different from open females (28.08 ± 0.31 µm), pregnant no milking females (28.17 ± 0.31 µm) and sires (27.74 ± 0.38 µm). Differences in fiber performance were found between ecotypes across all the defined groups, having on average 13% better performance the Huacaya according to textile criteria addressed by its lower diameter and variability.

A similar pattern was found for the other fiber related traits. Regarding the Huacaya ecotype, some of the physiological state groups were statistically suggested to be the same, being this regrouping very similar for FD as commented below. The lowest standard deviation was found for pregnant milking females (5.62 ± 0.06 µm), together with M (5.75 ± 0.07 µm) and O (5.75 ± 0.08 µm) slightly significantly higher in P females (5.99 ± 0.06 µm), and being relevantly and also significantly different from the sires that appeared as the most variables (6.34 ± 0.09 µm). Concerning Suri ecotype, females milking an offspring were the less variable (PM 6.79 ± 0.11 µm and M 6.88 ± 0.11 µm), but the most variable group was P for this ecotype (7.08 ± 0.11 µm), but not significantly different from O (7.03 ± 0.11 µm) and the sires (6.86 ± 0.13 µm).

Table 3
Number of records (n) and least squared means ± standard deviations of fiber traits in Huacaya and Suri ecotypes according to their physiological state. Groups with different letter are significantly different ($p < 0.05$).

Ecotype	State	N	FD (µm)	SD (µm)	CV (%)
Huacaya	PM	3367	24.46 ± 0.19^{a}	5.62 ± 0.06^{a}	23.18 ± 0.20^{a}
	M	1364	24.51 ± 0.24^{a}	5.75 ± 0.07^{a}	23.22 ± 0.26^{a}
	O	1459	25.16 ± 0.25^{b}	5.75 ± 0.08^{a}	22.91 ± 0.26^{a}
	P	1544	25.67 ± 0.19^{b}	5.99 ± 0.06^{b}	23.21 ± 0.19^{a}
	S	914	26.58 ± 0.28^{c}	6.34 ± 0.09^{c}	24.41 ± 0.27^{b}
Suri	PM	977	27.15 ± 0.30^{a}	6.79 ± 0.11^{a}	25.04 ± 0.30^{a}
	M	361	27.45 ± 0.31^{a}	6.88 ± 0.11^{a}	25.35 ± 0.32^{a}
	O	440	28.08 ± 0.31^{c}	7.03 ± 0.11^{bc}	25.15 ± 0.32^{a}
	P	312	28.17 ± 0.31^{cd}	7.08 ± 0.11^{bc}	25.47 ± 0.31^{a}
	S	320	27.74 ± 0.38^{b}	6.86 ± 0.13^{ac}	25.13 ± 0.37^{a}

(FD): fiber diameter; (SD): standard deviation; (CV): coefficient of variation; (O): open; (P): pregnant; (M): milking; (PM): pregnant and milking; (S): sires.

Table 4
Number of records (n) and least squared means ± standard deviations of fiber traits in Huacaya and Suri ecotypes according to their age group. Groups with different letter are significantly different ($p < 0.05$).

Ecotype	Age	n	FD (µm)	SD (µm)	CV (%)
Huacaya	3	59	23.05 ± 0.60^{a}	5.64 ± 0.18^{a}	22.70 ± 0.66^{a}
	4	1384	24.53 ± 0.14^{b}	5.77 ± 0.04^{a}	23.63 ± 0.14^{a}
	5	1235	24.74 ± 0.14^{b}	5.72 ± 0.05^{a}	23.31 ± 0.15^{ab}
	6	1079	25.72 ± 0.16^{c}	5.93 ± 0.05^{b}	23.34 ± 0.16^{ab}
	7	940	25.79 ± 0.17^{c}	5.90 ± 0.05^{b}	23.32 ± 0.18^{ab}
	8	844	26.34 ± 0.19^{d}	6.07 ± 0.06^{c}	23.44 ± 0.19^{ab}
	9	3107	26.76 ± 0.16^{e}	6.20 ± 0.05^{d}	23.97 ± 0.16^{ac}
Suri	3	16	25.03 ± 0.83^{a}	6.40 ± 0.30^{ab}	24.55 ± 0.95^{a}
	4	372	26.57 ± 0.26^{ab}	6.70 ± 0.09^{a}	25.13 ± 0.27^{a}
	5	316	27.18 ± 0.27^{b}	6.87 ± 0.10^{b}	25.49 ± 0.28^{b}
	6	323	28.26 ± 0.27^{c}	7.03 ± 0.10^{c}	25.39 ± 0.28^{c}
	7	294	28.46 ± 0.28^{cd}	7.08 ± 0.10^{c}	25.48 ± 0.30^{c}
	8	241	28.98 ± 0.30^{d}	7.14 ± 0.11^{cd}	25.28 ± 0.31^{d}
	9	848	29.55 ± 0.30^{e}	7.26 ± 0.11^{d}	25.26 ± 0.30^{e}

(FD): fiber diameter; (SD): standard deviation; (CV): coefficient of variation.

Results for coefficient of variation showed less significant differences given that this is a statistical parameter defined as the ratio between SD and FD. Nevertheless, there was also the similar rough trend, being the females under milking period the less variable, and being the males the most. For this trait in Huacaya the less variable animals were the O females (22.91 ± 0.26%) and the most variable the sires (24.41 ± 0.27), being the other groups intermediate. In the case of the Suri there were no differences between groups, but PM (25.04 ± 0.30%), S (25.13 ± 0.37) and O (25.15 ± 0.32) were the less variable groups while P (25.47 ± 0.31) and M (25.35 ± 0.32) were the most variable according to CV.

Significant differences between levels were analyzed as a secondary objective of this study and it is worth slightly mentioning about them. The least squared means, standard deviation and significant differences between levels of age effect on fiber traits are shown in Table 4, noting that FD, SD and CV tended to increase with the age of the animals, worsening the textile quality with the increase in the age. The interaction between physiological state and the age was significant in the Huacaya ecotype (Table 2), but this interaction was basically between pregnant and non-pregnant within both milking and non-milking females. All the groups roughly increased across years of age with those some minor interactions that could be attributed to random due to low number of animals in some categories. Instead the greater number of records for Huacaya ecotype allows finding clear differences between milking (M and PM) and not milking across all groups of age. Sires were significantly coarser than all female groups across ages, except for the youngest (three and four years old) in which they were not different from open females. This was probably due to differences in liveweight as reported by McGregor et al. (2016) in merino sheep, but liveweight has not been accounted in the model. Liveweight was assumed not be dependent on differences in feeding as it was completely uniform in the herd, being the animals fed *ad libitum* with a constant supplementation of forage. Of course, there must exist differences in liveweight related to age of the animals, but it was taken into account by fitting the age group. Conversely, fitting liveweight in the model would have removed an important part of the genetic component as a relevant genetic correlation between size and fineness has been reported (Cruz et al., 2016).

Table 5 shows the least squared means and standard deviation of fiber traits within year of recording, and the significant differences

Table 5
Number of records (n) and least squared means ± standard deviations of fiber traits in Huacaya and Suri ecotypes by year of recording. Groups with different letter are significantly different ($p < 0.05$).

Ecotype	Year	n	FD (µm)	SD (µm)	CV (%)
Huacaya	2001	34	21.13 ± 0.46^{a}	4.56 ± 0.14^{a}	19.34 ± 0.50^{a}
	2002	298	22.85 ± 0.23^{b}	5.48 ± 0.07^{b}	23.76 ± 0.24^{f}
	2003	478	23.25 ± 0.20^{c}	5.57 ± 0.06^{b}	23.71 ± 0.21^{f}
	2004	67	24.06 ± 0.33^{d}	5.53 ± 0.10^{bc}	23.08 ± 0.36^{cde}
	2005	771	24.75 ± 0.17^{e}	5.70 ± 0.05^{c}	22.82 ± 0.17^{bc}
	2006	632	28.01 ± 0.17^{i}	6.45 ± 0.05^{j}	22.92 ± 0.17^{cd}
	2007	482	28.59 ± 0.18^{j}	6.49 ± 0.05^{j}	22.59 ± 0.18^{b}
	2008	631	25.45 ± 0.17^{f}	5.94 ± 0.05^{d}	25.26 ± 0.17^{g}
	2009	726	26.77 ± 0.16^{h}	6.25 ± 0.05^{i}	26.91 ± 0.17^{h}
	2010	750	26.06 ± 0.16^{g}	6.06 ± 0.05^{ef}	23.15 ± 0.17^{de}
	2011	846	26.02 ± 0.16^{g}	6.04 ± 0.05^{de}	23.11 ± 0.16^{de}
	2012	872	25.48 ± 0.16^{f}	6.11 ± 0.05^{efg}	23.83 ± 0.16^{f}
	2013	692	25.81 ± 0.16^{g}	6.05 ± 0.05^{ef}	23.23 ± 0.1^{de}
	2014	639	25.51 ± 0.17^{f}	6.12 ± 0.05^{fgh}	23.79 ± 0.17^{f}
	2015	730	25.39 ± 0.16^{f}	5.97 ± 0.05^{de}	23.25 ± 0.17^{e}
Suri	2001	5	23.53 ± 1.17^{a}	3.56 ± 0.43^{a}	14.85 ± 1.47^{ab}
	2002	27	25.92 ± 0.59^{ab}	6.41 ± 0.21^{b}	25.59 ± 0.70^{c}
	2003	14	24.18 ± 0.75^{a}	6.18 ± 0.27^{b}	24.79 ± 0.92^{ad}
	2004	116	25.83 ± 0.36^{b}	6.45 ± 0.13^{b}	24.88 ± 0.40^{ae}
	2005	183	29.33 ± 0.32^{f}	7.40 ± 0.12^{de}	25.14 ± 0.34^{f}
	2006	205	28.16 ± 0.31^{c}	7.45 ± 0.11^{de}	26.30 ± 0.32^{g}
	2007	144	31.44 ± 0.33^{g}	7.67 ± 0.12^{f}	24.30 ± 0.36^{h}
	2008	197	28.29 ± 0.30^{cd}	6.99 ± 0.11^{c}	27.72 ± 0.33^{g}
	2009	214	29.29 ± 0.30^{f}	7.33 ± 0.11^{d}	28.69 ± 0.32^{i}
	2010	237	28.91 ± 0.30^{ef}	7.37 ± 0.11^{de}	25.42 ± 0.31^{f}
	2011	269	28.65 ± 0.29^{de}	7.33 ± 0.10^{d}	25.54 ± 0.30^{f}
	2012	252	28.17 ± 0.30^{c}	7.45 ± 0.11^{de}	26.25 ± 0.31^{g}
	2013	206	28.15 ± 0.31^{c}	7.46 ± 0.11^{de}	26.36 ± 0.33^{g}
	2014	161	28.17 ± 0.33^{cd}	7.56 ± 0.12^{ef}	26.55 ± 0.36^{g}
	2015	180	27.74 ± 0.34^{c}	7.30 ± 0.12^{d}	26.03 ± 0.35^{cg}

(FD): fiber diameter; (SD): standard deviation; (CV): coefficient of variation.

between them. There was also an important influence of the year of recording, with an increase in FD from 2001 to 2007 and decreasing afterwards to 2015. Fig. 1 shows this evolution of these least squared means for FD jointly with the breeding values obtained in the last routine genetic evaluation for this trait (Gutiérrez et al., 2014) in order to inspect if the differences across years have to be considered genetic trends or due to changes in the management. Results for SD and CV were always highly similar to those for FD.

Table 6
Least squared means and standard error of the effect of coat color to fiber traits in Huacaya and Suri ecotypes. Groups with different letter are significantly different ($p < 0.05$).

Ecotype	Color	n	FD (µm)	SD (µm)	CV (%)
Huacaya	White	5961	23.99 ± 0.11^{a}	5.25 ± 0.04^{a}	22.30 ± 0.12^{a}
	Cream	2196	24.76 ± 0.17^{b}	5.75 ± 0.05^{b}	23.39 ± 0.17^{b}
	Dark	491	27.08 ± 0.35^{c}	6.66 ± 0.11^{c}	24.47 ± 0.35^{c}
Suri	White	1534	25.05 ± 0.25^{a}	6.19 ± 0.09^{a}	24.96 ± 0.25^{a}
	Cream	702	27.17 ± 0.33^{b}	6.69 ± 0.12^{b}	25.06 ± 0.31^{a}
	Dark	174	30.98 ± 0.57^{c}	7.91 ± 0.20^{c}	25.66 ± 0.53^{a}

(FD): fiber diameter; (SD): standard deviation; (CV): coefficient of variation.

Finally, Table 6 shows the least squared means, standard deviation of fiber traits within coat color groups, and the significant differences between them. The influence of the color was also very important. Dark animals (27.08 ± 0.35 µm in Huacaya and 30.98 ± 0.57 µm in Suri) were much coarser than cream (24.76 ± 0.17 µm in Huacaya and 27.12 ± 0.33 µm in Suri) and white (23.99 ± 0.11 µm in Huacaya and 25.05 ± 0.25 µm in Suri) ones.

4. Discussion

Mean fiber diameter was generally found much higher than in previous works for this population (see for instance Cruz et al. (2016) for the last values) because only animals older than three years were considered in this analysis in order to avoid the influence of the extreme thinness of younger animals unable to be under pregnant and lactation status.

The results showed that there was an important influence of the physiological state effect of pregnancy and lactation on the fiber traits in alpacas. By comparing the diameters of the groups defined by the sex and physiological state, three non-overlapped statistical different groups were assessed: the finest were the females on lactation pregnant or not, the intermediate was defined by the non-milking females pregnant or not, and the other group was established for the males that resulted to be the coarsest, probably because of a higher live-weight. The groups were less clearly defined for Suri due to the lower

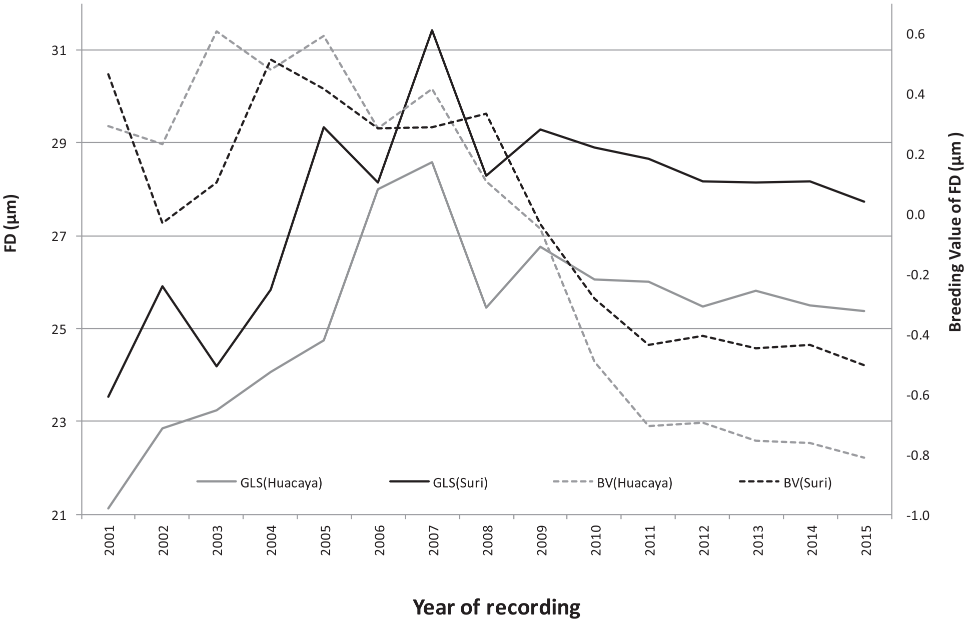

Fig. 1. Least Squared Mean (LSM) across years of recording (left axis) and Standardized Mean Breeding Values (BV) (right axis) for fiber diameter (FD) across years of birth in Huacaya and Suri ecotypes.

number of records but with a similar trend, being the pregnant milking females the thinnest and the sires the coarsest. Lactation therefore appeared as a very important event conducting to reduce the diameter in female alpacas, 0.65 µm in Huacaya and 0.63 µm in Suri in open females, and 1.21 µm in Huacaya and 1.02 µm in Suri in pregnant females. A better performance (lower diameter) of lactating females must be carefully taken, as an excessive lack of food leads to the well known "finesse of hunger" which produces breakable fibers, defective for the textile industry. This is not expected to be influencing here as the animals in this herd are *ad libitum* and uniformly fed. On the other hand, Ferguson et al. (2011) showed in sheep that if the diet decreases when a sheep is gestating and/or lactating, it can alter not only the weight of the newborn, but also the thickness of the fiber in the same animal, affecting the wool production and the reproduction efficiency through the live weight of the female. Pregnancy did not appeared as a significant effect, but in both cases M were coarser than PM females (0.05 µm in Huacaya and 0.30 µm in Suri) and P were coarser than O females (0.51 µm in Huacaya and 0.09 µm in Suri). This had already been studied in merino sheep, in which the effect of nutrition on the diameter of the wool and liveweight was found to be relevant in pregnant and lactating sheep, reducing the wool production between 0.4 and 0.7 kg, and the fiber diameter between 0.5 and 1.4 µm (Ferguson et al., 2011; Thompson et al., 2011). A similar reduction of fiber performance was found by poor nutrition in alpacas, with a loss of 0.95 kg of fleece weight, a reduction of 17 mm of staple length, and a reduction of 2.3 µm in the diameter but with an increase in the coefficient of variation of 1.8% in Huacaya ecotype (McGregor, 2002). On the other hand, nutrition can lead to changes in liveweight, influencing in turn the fiber performance. Thus, an increase of the liveweight of young angora goats resulted in an increase in fiber diameter of 1 µm that accumulated 2% more medullated fiber, but old angora goats were not strongly influenced by this factor (McGregor et al., 2013a, 2013b), but as commented above it is not expected to be determinant here. Nevertheless gestation and early lactation have been found to have effect on the production of medullated fibers in cashmere goats (Celi et al., 2010b). Literature is not completely consistent regarding the influence of lactation and gestation on fiber, concerning Southamerican camelids, Celi et al. (2010a) reported that the lactation would not have a significant effect on the quantity and quality of the fiber. Females with an overlapping physiological state between gestation and lactation in cashmere goats suggested that the energy expenditure should be greater in comparison to open females and non-lactating (Celi et al., 2010a, 2010b). In this case, in alpacas, the energy deposition seems to be similar than the energy expenditure needed for the formation of the fetus when females are pregnant unlike lactation state in which negative energy balance appeared much stronger. However, it has to be noted that the fiber sample was taken during the shearing around the eighth gestation month. At this stage the energy demanding has not been high yet, and, in addition, note that the mean diameter is an average of all the fiber in its length, including initial periods of the gestation in which no demanding existed. The appearance of the fleece is known to be also different in pregnant alpacas looking brighter and healthier. However, the milk synthesis implies a high nutrient demand during lactation becoming larger than the energy deposition. In this sense, alpaca milk composition is lower than in sheep, close to the values reported for goats and cattle, and very similar to the camels (Degen, and Chad et al., 2007, 2014). This low energy composition regards with the environment the alpaca lives. The feeding is relegated to low nutritional levels pastures needing to cover milk production by mobilization of the body reserves, with a low neonates mortality that could be explained by starvation due to lack of milk in the mothers (Mamani et al., 2009). On the other hand, energy demand can be balanced by the increase in diameter hypothesized by Celi et al. (2010a).

All the other effects were found to be highly influencing fiber performance. The analysis of their influence was not the main aim in this work, but they were fitted to reduce the residual variability in order to stand out the affection of the physiological state. However, some findings merit commenting them. Concerning the age of the animals, it is well known that there is a linear and quadratic linear relationship confirmed here (Tables 2 and 4), even when for this work records have been restricted to those from adult animals. The fiber diameter follows a linear pattern across life in the early years, and then tending to become stable (Gutiérrez et al., 2011; McGregor and Butler, 2004). Tables 3 and 4 shows the means of fiber diameter (FD) for the different sex and physiological state of females across ages groups in Huacaya and Suri ecotypes. Even when the above commented influence of age is the general rule, and it is almost fulfilled for milking (PM and M) females in the Huacaya ecotype, there seems to be some interactions, but they must be taken with caution because a no so high number of records in some categories of physiological state. The correlated influence of age on the standard deviation is easily explained by the genetic correlation among all fiber traits, and it was shown also to be related with the variability across repeated measures of fiber throughout the animal life (Gutiérrez et al., 2011). It was also observed in sheep that the sex and the age of lambs influenced most of the default traits evaluated; however sex showed no influence in the fiber diameter, comfort factor and rate of fiber medullation (Cilek, 2015).

Finally, coat color had also an important influence on the fiber performance, being for example dark coat animals 3.09 µm coarser than white ones in Huacaya, and 5.93 µm in Suri. This was already reported by McGregor and Butler (2004). Parallel differences were found for the other fiber traits showing the importance of considering the effect in the model. However in the case of the sex of the animal, that was not found important by Gutiérrez et al. (2011) for the genetic evaluation, now it become important when females are classified according to their physiological state.

The influence of the year of recording on performances was also proven, as it was highly significant. Part of this effect gathers environmental circumstances related to climatic influence or maybe market conditioning or management changes, but it also collect genetic differences between animals as a consequence of the successful artificial selection process carried out in the herd as reported by Gutiérrez et al. (2014). Fig. 1 shows the influence of the year of recording together with the mean breeding values across years. It shows that there was an increase in the fiber diameter mean from 2001 to 2007, but the genetic evolution in this period was roughly flat. However, from 2007 onwards there was an important slope in the evolution of the genetic component that strongly contributed to a reduction in the fiber diameter during this second period. Thus, the figure suggests that the influence of the year on FD was mainly environmental until 2007, having an important genetic explanation afterwards.

The influence of the lactation and pregnancy on the fiber performance has been here quantified in alpacas. It was previously well known, also on the wool of merino sheep (Ferguson et al., 2011; Thompson et al., 2011) and cashmere goats (Celi et al., 2010a, 2010b). The findings here carry implications in the model to be used to obtain the genetic parameters of these traits and the breeding values of the animals. In fact, and in order to remove its influence on the measurements and accuracy of the methodology of fiber diameter, it was established that sample readings should be cut in snippets of 2 mm along the sample (Phillips et al., 1992), thus averaging the diameter across all the physiological states of the animal. Nevertheless, this only superficially makes up the influence on the fiber traits, and actions are concluded here to be required in the genetic evaluation process. Currently the model included an effect defining the contemporary group, the sex, the age and the coat color of the animal (Cervantes et al., 2010). Now we know that the physiological state importantly affects the fiber performance. Therefore it would be advised to split the female level of the fixed effect in several levels according to its physiological state, with one or two additional levels regarding too young animals, but including somehow, probably as a covariate, the age of the animal as an additional effect.

5. Conclusion

The physiological state of the females had an important effect on the fiber performance, non-lactating females having the largest fiber diameter and pregnant lactating females the thinnest. Methodology has been developed in order to adjust the influence of the physiological state of the animal but it has been proven here not completely correct it. The relevant differences found in this study among physiological states, mainly lactation, suggests that these states should have to be accounted in the models routinely used to estimate genetic parameters in order to increase the breeding values accuracy, and to obtain a faster genetic progress in a population of animals mostly in hands of small producers needing to increase their incomes to improve their wellness.

Conflict of interest

There is no conflict of interest for this paper.

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