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Genetic and non-genetic factors influencing fibre quality of Bolivian llamas

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Abstract
Llamas display a great variability of fibre traits that determine the quality of the fleece as raw material for textiles. Little research has been conducted on the extent of this variability, although it is important for optimal use of natural resources in the Andean region. Fibre samples of 1869 llamas were analysed with the optical fibre diameter analyser (OFDA). The following traits were considered: Mean fibre diameter (MFD), standard deviation (SD), diameter of fine fibre (DFF), proportion of fine fibre (PFF), proportion of kemp (PK) and proportion of medullated fibre (PMF). The effects of type of llama, age, sex and coat colour were studied. The type of llama influences all traits showing that Th´ampulli (fibre type) is better than Kh´ara (meat type). With increasing age of the animal MFD, SD, DFF and PK increased whereas PFF decreased. Comparing the two sexes, females showed better fibre quality. Light coat colours tend to be of better quality than darker ones.
Heritabilities and genetic correlations were estimated using animal model procedures where all information came from mother-offspring relationships. Heritability estimates were 0.33, 0.28, 0.36, 0.32 and 0.25 for MFD, SD, DFF, PFF and PK, indicating potential for genetic selection.

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1 Introduction
In Bolivia 2.4 mio llamas are kept in the marginal areas of the High Andes (UNEPCA 1999). Llamas are very well adapted to the harsh environment and provide the farm households with a varity of products such as meat, fibre, dung and are used as pack animals. A large part of the products is consumed in the household and sale of meat and fibre is irregular. Absence of infrastructure and unsteady quality and quantity of fibre are main factors preventing a more market oriented llama husbandry. Llama fibre generally has a bad reputation for being coarse and is therefore not used in the textile industry. However Delgado (2003) and Iñiguez et al. (1998) showed that there are subpopulations in Bolivia with a high fibre quality.

2 Material and Methods

The study was carried out in 4 indigenous communities of the eastern slope of the Andes in Bolivia, in the Province of Ayopaya, Department Cochabamba (66°30`S, 17°00`W). The communities are located between 3800 and 4300 m above sea level.

Data collection took place between November 1998 and January 2001. A total number of 2533 fibre samples were taken from the left side of the animals. The weight of each sample was between 5 and 10g. Multi-coloured samples and samples from animals older than 7 years were not used for analysis. Samples were classified in 6 colours: white, beige, light fawn, brown, grey and black.

Two types of llamas were distinguished. Th`ampullis are regarded as “fibre-type” with finer fibre and higher fleece weight. Kh`aras are a more meat oriented type. Both types are kept together in herds and mating between these two types occurs frequently. Classification of types was done by farmers. Age of the animals was identified by denting for young ones and relied on information from farmers for older animals. Distribution of sexes and types according to colour is shown in Tab 1.

Table 1. Total numbers (n) and distribution (in percent) of types and sexes by colours. Only single–coloured animals are considered.

	n	white	beige	light fawn	brown	grey	black
Kh`ara female	156	9.6	20.5	1.9	56.4	7.7	3.8
Th`ampulli female	1249	10.0	17.5	4.9	52.8	8.8	5.9
Kh`ara male	33	9.2	24.3	3.0	51.5	6.0	6.0
Th`ampulli male	431	11.4	16.5	7.4	47.3	10.0	7.4
total	1869	10.3	17.7	5.2	52.0	8.9	6.0

Laboratory analysis

Analysis of fleece characteristics were conducted in the wool laboratory of University Hohenheim, Stuttgart, Germany. Every raw sample was blended, scoured, dried and conditioned in a standard atmosphere (20^{o}C ± 2^{o}C and 60% ± 2% rH). Snippets of 2 mm length were cut with a guillotine and spread on an open glass slide using an automatic spreader. Then the slides were analysed by OFDA (Optical Fibre Diameter Analyser) according to IWTO-47-95 standard (IWTO 1995). 3000 to 6000 measurements per sample were carried out.

The following traits were analysed:

Mean fibre diameter (MFD) which is the most important trait for fibre quality. Standard deviation of the mean fibre diameter (SD) is an indicator for the homogenity of the fleece. Diameter of fine fibre (DFF) and proportion of fine fibre (PFF) as indicators for the quality of the under coat. Proportion of medullated fibre (PMF) is defined by the OFDA as the proportion of fibres with an opacity of ≥ 80%. Only data from white samples were used for this trait, because OFDA seems to overestimate this proportion in coloured fibres (Delgado et al. 1999). Proportion of kemps (PK) is defined by the OFDA as the proportion of fibres with an opacity of ≥ 94% and diameter larger than 25 µm. Kemp is a technical term referring to a fraction of medullated fibres.

Traits were tested for normal distribution and transformed when necessary. Only DFF showed a normal distribution. A logarithmic transformation (y = log x) was performed for MFD, SD was transformed with a trigonometric function (y = atan x), PFF with a logarithmic function (y = log(x/(100-x)), PMF with the square root function (y = $\sqrt{x/100}$) and PK with the function of Box and Cox (y = (($x^{0.2}$-1)/0.2)-1) (Delgado 2003).

Statistical analysis

The following statistical models were used:

Model 1

$Y_{ijklmn} = \mu + F_i + A_j + S_k + T_l + C_m + YS_n + (A*S)_{jk} + e_{ijklmn}$

Y_{ijklmn} = transform of mean fibre diameter, diameter of fine fibre (<30µm)

Model 2

$Y_{ijklmn} = \mu + F_i + A_j + S_k + T_l + C_m + YS_n + e_{ijklmn}$

Y_{ijklmn} = transform of standard diviation of mean fibre diameter

Model 3

$Y_{ijklmn} = \mu + F_i + A_j + S_k + T_l + C_m + YS_n + (A*S)_{jk} + (A*T)_{jl} + e_{ijklmn}$

Y_{ijklmn} = transform of proportion of fine fibre

Model 4

$Y_{ijklmn} = \mu + F_i + A_j + S_k + T_l + C_m + YS_n + (A*T)_{jl} + e_{ijklmn}$

Y_{ijklmn} = transform of proportion of kemp

Model 5

$Y_{ijklm} = \mu + F_i + A_j + S_k + T_l + YS_{ml} + e_{ijklm}$

Y_{ijklm} = transform of medullated fibre

with

μ_i = constant common to all individuals;

F_{ij}= fixed effect of farmer j, j = 1,65;

A_j = fixed effect of age j, j = 1,5 (j = ≤ 0.5, > 0.5 - ≤ 1, >1 - ≤ 3, >3 - ≤ 5, > 5 - ≤ 7);

S_k = fixed effect of sex k, k = 1,2 (male, female);

T_l = fixed effect of type l, l = 1,2 (Th`ampulli, Kh`ara);

C_m = fixed effect of colour m, m =1,6 (white, brown, black, light fawn, beige, grey);

YS_n = fixed effect of year-season n, n = 1,3 (Nov. 1998, Oct. 1999 to Feb. 2000, Oct. 2000 to Jan. 2001);

$(A*S)_{jk}$ = effect of interaction between age and sex;

$(A*T)_{jl}$ = effect of interaction between age and type;

e_{ijklmn} = random residual effect;

Estimation of fixed effects was carried out with the GLM procedure of SAS (SAS 1999). The effect of the interval between sampling and last shearing was tested and showed no significant influence. Tukey`s test was performed for pairwise comparison of group means. The values presented in Table 2 are least squares means of the untransformed data, the attached probabilities and tests relate to the transforms. This procedure was followed as backtransformation of least squares means of transformed values is mathematically inappropriate.

To estimate genetic parameters, all traits were joined in a mulitvariate model and a random additive genetic animal effect was added. The relationships included were all of the type mother-offspring. The estimation was carried out with the VCE program (Neumaier and Groeneveld 1998).

3. Results and Discussion

Comparison of results from literature with the results presented here is difficult. Different methods such as air flow, microprojection or OFDA are used in laboratories for determing fibre traits. In addition it is not always clear if published figures come from complete or dehaired fleeces and definitions for some traits such as kemp or medullated fibre vary.

Table 2 provides an overview of the fixed effects.

Types

Th`ampullis are superior to Kh`aras in all fibre traits. Th`ampullis showed a significantly lower MFD than Kh`aras and a significantly more homogenous fleece. Iñiguez et al. (1998) recorded the lowest MFD of 21.1 µm in a population in the South of Bolivia, but without differences between types. Parra (1999) could not find differences between both types regarding MFD. Whereas Marti et al. (2000), Súmar (1991) and Maquera (1991) reported differences between types.

Diameter of fine fibre was significantly lower in Th`ampullis, but with similar proportion of fine fibre in both types. In contrast Ayala (1999) found similar DFF, but a significant higher proportion of fine fibre in Th`ampullis. The proportion of Kemp for Kh`aras is 0.75% and for Th`ampullis 0.10%. Both Iñiguez et al. (1998) and Parrra (1999) give much higher values, but this is due to different definitions of the trait and differences in laboratory analysis.

Sex

Differences between sexes are significant for MFD, DFF and PFF. Males have coarser fibre (MFD: 22.54 ± 7.32 µm) than females (MFD: 21.96 ± 7.37 µm) and a lower PFF. These results correspond with the findings of Chávez (1991). Whereas Ayala (1999), Martinez et al. (1997) and Iñiguez et al. (1998) could not find differences. For the traits PK and PMF no differences could be found. These results are in agreement with Iñiguez et al. (1998), but contrary to other studies (Ayala 1999, Martinez 1997, Marti et al. 2000).

Age

With aging MFD, SD, DFF and PK increase and at the same time PFF decreases.

Animals between 1 and 3 years have fine fibre with 22.08 µm with a standard deviation of 7.42 µm. The first shearing is recommended at the age of 2 years and should be organized in similar age groups (Martinez et al. 1997). These results are in accordance with reports from other authors (Chávez 1991, Iñiguez et al. 1998, Marti et al. 2000, Martinez et al. 1997, Parra 1999).

Colour

MFD and DFF is lower and at the same time PFF is higher in light colours than dark ones. SD is smallest for the colour beige and highest for black. These results are contradictory to the findings of Iñiguez et al. (1998) where white fibres were thicker than coloured ones. Parra (1999) and Martinez et al. (1997) did not find differences between colours.

Table 2 . LSMeans of different fibre traits

	n	MFD (μm)	SD (μm)	DFF (μm)	PFF (%)	PK (%)	n	PMF (%)
Kh`ara	189	22.78[a]	8.09[a]	20.77[a]	88.67[a]	0.75[a]	18	34.35[a]
Th`ampulli	1680	21.71[b]	6.59[b]	19.90[b]	89.26[b]	0.10[b]	175	14.58[b]
female	1405	21.96[a]	7.37[a]	20.14	89.94[a]	0.45[a]	141	23.89
male	464	22.54[b]	7.32[b]	20.53	88.00[b]	0.40[b]	52	25.03
age								
0 - <=0.5	130	20.68[a]	7.12[a]	19.08[a]	90.44[a]	0.15[a]	18	32.48
>0.5 - <=1	501	20.19[a]	6.66[b]	18.97[a]	94.03[b]	0.38[b]	54	23.72
>1-<=3	489	22.08[b]	7.42[c]	20.30[b]	90.59[a]	0.50[c]	44	23.82
>3-<=5	444	23.81[c]	7.62[c]	21.45[c]	85.15[c]	0.54[c]	48	19.73
>5-<=7	305	24.48[c]	7.90[d]	21.87[c]	84.62[c]	0.55[c]	29	22.56
colour								
white	193	21.99[a]	7.15[a]	20.19[a]	89.54[ab]	0.40[bc]		
beige	330	21.87[a]	7.41[ab]	20.07[a]	90.13[a]	0.45[ab]		
light fawn	97	21.96[a]	7.27[ab]	20.12[ab]	89.34[abc]	0.45[abc]		
brown	968	22.63[b]	7.43[b]	20.63[c]	88.33[bc]	0.44[a]		
grey	167	22.14[ab]	7.41[ab]	20.25[ab]	89.17[abc]	0.43[abc]		
black	114	22.89[b]	7.40[ab]	20.74[cb]	87.27[c]	0.37[c]		
year x season								
JS = 1	743	22.80[a]	7.57[a]	20.61[a]	87.18[a]	0.42	83	23.98
JS = 2	897	21.43[b]	7.18[b]	19.80[b]	91.11[b]	0.41	86	24.84
JS = 3	229	22.52[a]	7.29[ab]	20.59[a]	88.61[c]	0.45	24	24.57
Interaction age x sex[A]								
0 - <=0.5 x female	64	20.54		18.98	91.24			
0 - <=0.5 x male	66	20.82		19.18	89.64			
>0.5 - <=1 x female	261	20.23		19.00	93.92			
>0.5 - <=1 x male	240	20.14		18.94	94.14			
>1-<=3 x female	364	22.25		20.41	90.23			
>1-<=3 x male	125	21.92		20.19	90.95			
>3-<=5 x female	421	23.03[a]		20.98[a]	87.81[a]			
>3-<=5 x male	23	24.59[b]		21.91[b]	82.50[b]			
>5-<=7 x female	295	23.75		21.33[a]	86.48[a]			
>5-<=7 x male	10	25.22		22.41[b]	82.75[b]			
Interaction age x type[B]								
0 - <=0.5 x Kh`ara					88.14	0.23		
0 - <=0.5 x Th`ampulli					92.74	0.07		
>0.5 - <=1 x Kh`ara					93.84	0.70[a]		
>0.5 - <=1 x Th`ampulli					94.22	0.06[b]		
>1-<=3 x Kh`ara					90.80	0.90[a]		
>1-<=3 x Th`ampulli					90.38	0.10[b]		
>3-<=5 x Kh`ara					84.72	0.98[a]		
>3-<=5 x Th`ampulli					85.59	0.10[b]		
>5-<=7 x Kh`ara					85.86[a]	0.96[a]		
>5-<=7 x Th`ampulli					83.38[b]	0.15[b]		
R^2		0.41	0.31	0.42	0.35	0.39		0.47
s_e		0.10	1.17	1.46	0.59	1.08		0.14

MFD = mean fibre diameter, SD = standard diviation of MFD, DFF = diameter of fine fibre, PFF = proportion of fine fibre, PK = proportion of kemp, PMF = proportion of medullated fibre

a, b, c: different letters indicate significant differences al P=0.05. [A]tests of significans only between the two sexes within age group. [B]test of significances only between the two sexes within types.

Heritabilities and genetic correlations
Estimates of heritabilites and genetic correlations for different fibre traits are shown in Table 3.

Table 3. Estimates of heritabilities (diagonal), genetic correlations (above diagonal) and correlation of residuals (below diagonal) of different fibre traits

	MFD	SD	DFF	PFF	PK
MFD	*0.33 ± 0.05*	0.62 ± 0.07	0.96 ± 0.008	-0.94 ± 0.02	0.37 ± 0.11
SD	0.71 ± 0.05	*0.28 ± 0.05*	0.44 ± 0.09	-0.72 ± 0.06	0.72 ± 0.07
DFF	0.97 ± 0.05	0.59 ± 0.05	*0.36 ± 0.05*	-0.82 ± 0.04	0.33 ± 0.11
PFF	-0.92 ± 0.06	-0.72 ± 0.06	-0.83 ± 0.06	*0.32 ± 0.06*	-0.25 ± 0.13
PK	0.47 ± 0.05	0.60 ± 0.05	0.42 ± 0.05	-0.35 ± 0.05	*0.25 ± 0.05*

MFD=mean fibre diameter, SD= standard diviation of MFD, DFF= diameter of fine fibre, PFF = proportion of fine fibre, PK = proportion of kemp, PMF = proportion of medullated fibre

In llamas data of heritabilities for different fibre traits are rare. Results presented here are in line with Frank et al. (1996) who reported for fibre diameter a heritability of 0.29 and for standard diviation of 0.23. The highest positiv genetic correlation was found between MDF and DFF. Selection for a lower MFD will change DFF in the same direction. At the same time the PFF will increase and the SD will decline. By improving the fibre diameter the homogenity of the fleece will therefore also be better.

4 Conclusions

The llama population in Ayopaya shows a high genetic potential for high quality fibre production. Fleece weight was missing to make more general conclusions. Improvements in the management and breeding strategies should be carried out at the same time. Improvements of management include shortening of shearing intervall, separation of wool according to colour and fibre diameter.

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