Variation of commercially important characteristics among sampling sites for vicuña (*Vicugna vicugna mensalis*) fleeces

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Abstract

The aim was to evaluate variations in important commercial characteristics of vicuña fibre, and to determine the best areas for sampling and classification of vicuña fleece. Fibre samples were taken from 30 vicuña (males = 15, females = 15; adults = 10, juveniles = 10, cria = 10) at 12 body sites: neck (N), forelimb (FL), hindlimb (HL), anterior saddle (AS1, AS2 and AS3), central saddle (CS1, CS2 and CS3) and posterior saddle (PS1, PS2 and PS3). Samples were taken during the annual capture of vicuña (*chaku*), at Saccsalla (4700 m above sea level), the Research Center of South American Camelids, at Lachocc (Huancavelica, Peru), and part of the National University Huancavelica (UNH). The fibre samples were examined with the Optical Fibre Diameter Analyzer (OFDA2000) at the UNH Laboratory of wools and fibres. Results indicate that the source of variation among regions is relatively high (> 30%) for the average fibre diameter (AFD), the coefficient of variation of fibre diameter (CVD), the spinning fineness (SF) and fibre curvature (FC). There was evidence that age, gender and sampling site affected these fibre characteristics. It was determined that the area CS3 (located 10 cm from the dorsal linear on the 10th rib, near the mid back) was the best site sampling for ADF and SF studies. This result differs from earlier reports on the best sampling site to evaluate fleeces of alpacas, sheep and Angora goats.

Keywords: Fibre curvature, fibre diameter, fibre diameter variation, sampling site, vicuña.

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Introduction

The smallest South American camelid, the vicuña (*Vicugna vicugna*), is a rare wild animal. It is found over much of the high altitude zone of Perú (3000 m to 5000 m), and it is also found in Bolivia, Chile, Argentina and Ecuador. The vicuña has a double-coated fleece, with coarser guard hair fibres, and an abundant fine undercoat of shorter (down) fibres. The average diameter of fine fibres ranges between 10.8 and 16.0 μm (Quispe et al., 2009). The vicuña has been captured, handled and sheared since the 15th century, when the Inca Empire conducted the "*chaku*" throughout the Andes region of South America. The chaku consisted of herding thousands of vicuña into stone corrals for shearing (Bonacic, 2005). In Peru the chaku is conducted each year to avoid indiscriminate hunting.

The sale of vicuña fibre is an important economic resource for many Peruvian communities. These communities are responsible for the captive management of vicuña in fenced areas with up to 1000 ha (Vilá, 2002). Under Peruvian law, the fibre can be harvested by the community while the animals remain the property of the state (usufruct) (Quispe et al., 2010).

Two subspecies of vicuña have been described. The first (the southern), *Vicugna vicugna vicugna* is said to occur between 18° and 29°S latitude, while the second, the northern *Vicugna vicugna mensalis,* is reported between 9°30' and 18°S latitude (Wheeler, 1995). Subspecies classification is based upon differences in morphology, including length of molars, height of withers, length of chest hair and pelage colour (Sarno et al., 2003). The subspecies *mensalis* has a dark cinnamon colour and white pectoral hairs with abundant coarse fibre, and the subspecies *vicugna* has a more whitish pelage, is larger and has no white pectoral hairs (Yacobaccio, 2006).

The price of dehaired vicuña fibre can vary between $US 300–800 per kg. Assessment of vicuña fibre is mainly related to its fine fibre diameter (Bonacic, 2005; Cardellino and Mueller, 2009; Quispe et al., 2009; Quispe et al., 2010) and rarity (Watson and Buxton, 1992). However, other textile properties that are important during processing and for raw fibre classification, such as coefficient of variation of fibre diameter, fibre curvature, tensile strength and softness, have been little studied and there are few reports about these attributes (Quispe et al., 2010; McGregor, 2014).

Fibre diameter and its variation over the body are the most important parameters of the fleece from a textile and technological point of view, so their determination is essential to qualify and establish the price of fibre (Carpio, 1991). It has been determined in Merino sheep that the components of total variance of fibre diameter within a herd are: a) variation between fleeces, b) variation between body sites, c) variation between fibres within a staple, and d) variation along a fibre. The contributions to total variation of fibre diameter for each of these sources of variation were: 16, 4, 64 and 16% respectively (Hansford, 1992). Therefore it is important know the body region or sampling site that best represents the whole fleece, because it is known that the technological characteristics of the fleeces vary between different body parts of the animal, such as was determined in sheep (Doney and Smith, 1961; Tabbaa et al., 2001; Fish et al., 2002), goats (Newman and Paterson, 1999; Taddeo et al., 2000; McGregor and Butler, 2008) and alpacas (Newman and Paterson, 1996; Aylan-Parker and McGregor, 2002; McGregor et al., 2012). Several studies have concluded that the fibre diameter at the 10th rib region is the most representative site for predicting the average diameter of the whole fleece in Merino sheep and alpacas (Turner et al., 1953; Saddick, 1993; Aylan-Parker and McGregor, 2002). This approach has been used with vicuña fleece, but there has been little research to confirm this approach as the most suitable for the characterization and classification of vicuña fleece.

For these reasons, the aim of this study was to evaluate the different technological characteristics of the vicuña fibre at different sites of the body for variability of characteristics and to subsequently determine the best site to sample in order to assess the whole vicuña fleece.

Materials and methods

This work was carried out at the Research Center of South American Camelids. The center is located in the Puna ecosystem of Lachocc community (4700 m above sea level) in Huancavelica, Perú. The vicuña population of the station comprised approximately 300 animals living at Saccsalla on a corral of 500 ha. The area has water available and natural pasture, of which the predominant species are *Poaceae*, *Cyperaceae*, *Asteraceae* and *Juncacea* families (Quispe et al., 2010).

On 14 October 2011 a *chaku* was held and fibre sampling was conducted. During the *chaku*, 150 people organized into different groups and under the direction of a supervisor, formed human chains in order to direct groups of vicuña to a management yard. As shown in Table 1, 131 vicuña were captured, and 83 were shorn using a Heiniger shearing machine. Only animals over 1 year of age, without health problems, and with more than 2.5 cm fibre length measured at the mid rib site, were shorn. The average weight of harvested fleece was 190 g.

Prior to shearing, fibre samples were taken from 30 vicuñas representing both sexes and three age classes. From each vicuña, fibre samples were taken from 12 body sites (Table 1) as follows: neck (N), forelimb (FL), hindlimb (HL), anterior saddle (at three levels from ventral to dorsal: AS1, AS2 and AS3), central saddle (CS1, CS2 and CS3) and back saddle (BS1, BS2 and BS3), as shown in Figure 1.

Fibre samples were kept in sealed paper envelopes, for fibre analysis, performed by means of the Optical Fibre Distribution Analyzer (OFDA2000) at the Laboratory of Wools and Fibres of the UNH (Brims et al., 1999). Prior to analysis, the staple length was measured using a millimetre ruler. The average fibre diameter (AFD, µm), fibre diameter coefficient of variation (CVD, %), spinning fineness (SF, µm) and fibre curvature (FC, º/mm) were measurements with OFDA2000.

Kolmogorov-Smirnov and Levenne tests were used to evaluate normality and variance homogeneity, respectively. CVD and FC required transformation, respectively trigonometric arc sine and logarithmic functions for subsequent statistical processing (Kuehl, 2000). The varComp-package of R (Qu et al., 2013) was used to obtain variance components estimates of fibre characteristics between fleeces (or animals), within fleece (sites) and residual, using the best mixed-effect model: $y_{ijklm}=\mu+Sex_i+Age_j+Animal_k+Site_l/Animal_k+e_{ijklm}$, with Sex and Age as fixed effects and Site and Animal as random effects. A Duncan test was used for comparison among fibre characteristics from different sampling sites

Pearson correlations for 5 characteristics in each sampling site were calculated to determine the best sampling area. A correlation matrix was constructed and those having the value close to 1 were considered the best sample area of vicuña fleece. Additionally, forward stepwise regression analyses for each fibre characteristic, considered as an independent variable, and the average fleece value considered as the dependent variable corresponding to each sampling site, were performed. Statistical analyses were performed using R software (v. 3.0.2).

Results

Sources of variation of characteristics of vicuña fibre

The study estimated three variance components for each of the fibre characteristics: a) the variation among animals, corresponding to the variation among fleeces (VAF); b) variation within animals, corresponding to the variation among regions of the fleeces as represented by the different sampling sites (VAR/F); and c) the residual variance, which in turn contains 2 sub sources: the variation among fibres and variation across fibres within regions and within the fleeces (VR/R/F). The values of these variance component estimates appear to be low, with ranges for AFD, CVD and SF as follows: 0.34 to 0.49 µm^2; 0.94 to

Table 1. Number of vicuñas captured, shorn and sampled in the "chaccu" 2011 in the CIDS-Lachocc of UNH, by sex and age stratum.

	Vicuñas captured	Vicuñas shorn	Vicuñas sampled
Female	61	34	15
- Crias	11	0	5
- Young	5	2	5
- Adult	45	32	5
Male	70	49	15
- Crias	8	0	5
- Young	9	8	5
- Adult	53	41	5
TOTAL	131	83	5

Table 2. Sources of variation or variance components of average fibre diameter (AFD), fibre diameter coefficient of variation (CVD), spinning fineness (SF), fibre curvature (FC) and staple length (SL) and their relative contribution to total variance for each fleece attribute (%).

Sources of	AFD		CVD		SF		FC		SL	
variation	Value	%	Value	%	Value	%	Value	%	Value	%
Between animals	0.34	28.3	0.94	19.9	0.26	20.3	14.55	16.7	1.91	3.7
Within animals	0.38	31.2	1.42	30.2	0.49	38.5	8.60	9.9	35.19	67.5
Residual	0.49	40.5	2.34	49.9	0.52	41.2	63.73	73.4	15.00	28.8
Total	1.22	100.0	4.70	100.0	1.27	100.0	86.88	100.0	32.68	100.0

2.34; 0.26 to 0.52 μm^2 respectively (Table 2). With respect to the component of variance VAR/F, this constitutes about one-third of the total variation of the variance for AFD, CVD and SF, while for FC VAR/F contributes only about 10% of the variance. For SL, VAR/F contributes about two-thirds of the total variance.

The variance among fleeces component constitutes about 20% of the total variance for the AFD, CVD, SF and FC (Table 2). For SL, variation among fleeces represented less than 5% of total variance (Table 2), probably due to the fact that animals selected for shearing had to have a SL ≥ 25 mm, which is the minimum SL for textile processing on the carding system. The estimated residual variation constituted 40–50% of the total variation for AFD, CVD and SF, almost three-quarters of total variation for FC (Table 2).

Variation of fibre characteristics with sampling site

Averages of AFD, CVD, SF, FC and SL found in each sampling site are shown in Table 3. Specifically site AS3 has previously been identified as the best sampling site for estimating the AFD of the whole fleece in Merino sheep (Chapman and Young, 1957). The ventral sampling sites (AS1, CS1, BS1) had the coarser fibres. The neck had fine fibres but these were the shortest fibres (Table 3).

Determination of the sampling area for different characteristics of vicuña fleece

The highest correlations between the fibre characteristic at each sampling are summarized in Table 4. The highest correlations found between the fibre characteristics of each sampling site ranged from a low of 0.76 for SL to a high of 0.92 for AFD and CVD (Table 4). Sampling site CS3 had the highest correlation between the AFD of any site and the ADF of the whole fleece, whether or not the neck was included, with a similar result for SF. For the CVD, FC and SL the sample sites with the highest correlation with the whole fleece measurement were respectively: BS2, AS3 and CS1 (Table 4).

Table 5 shows the relationship between the fibre tests from sampling site CS3 and the average for all the samplings sites for each fleece characteristic. The difference between the measurement of AFD, CVD, SF and FC, at site CS3 and the fleece average are small, ranging from 0 to 3%, but for SL the difference is -7% (Table 5). Similarly, the correlation coefficient between site CS3 and the fleece average measurement is high for AFD, CVD and SF but low for SL (Table 3).

Table 6 shows simple linear regression models for the prediction of mean fleece characteristics using only one sampling sites, corroborating sampling sites obtained by correlation.

Discussion

The values of the three variance component estimates for the AFD, CVD and SF of vicuña fleeces are lower than that found in alpaca fleeces (Aylan-Parker and McGregor, 2002; Manso, 2011), sheep fleeces (Doney and Smith, 1961; Saddick, 1993; Fish et al., 2002) and mohair fleeces (McGregor and Butler, 2008). This indicates the vicuña fleeces are more homogeneous with respect to these three characteristics, in comparison with other species producing fibre or wool fleeces.

The result that VAR/F provides about one-third of the total variation, supports the need for a representative fibre sample for the purposes of characterization and classification of fleeces from vicuñas, according to these characteristics, which mainly define the quality of the fibre for

Table 3. Average and standard error (se) of average fibre diameter (AFD), fibre diameter coefficient of variation (CVD), spinning fineness (SF), fibre curvature (FC) and staple length (SL) of vicuña fibre at different body sites. The average for all the fleece sites is shown (A Fl).

	AFD ± se (µm)	CVD ± se (%)	SF ± se (µm)	FC ± se (°/mm)	SL ± se (mm)
Neck	13.9± 0.21^{bc}	20.7±0.41^{cde}	13.5±0.22^{bcd}	82.1 ±1.94^{ab}	19.3±0.56^{a}
Forelimb	14.0±0.18^{bc}	20.1±0.39^{bcd}	13.5±0.17^{bcd}	83.6 ±1.59^{abc}	22.6±0.54^{b}
Hindlimb	13.9±0.18^{bc}	18.7±0.37^{a}	13.3±0.16^{bc}	87.9 ±1.75^{c}	24.0±0.58^{b}
Anterior saddle 3	13.2±0.22^{a}	19.6±0.36^{abc}	12.7±0.20^{a}	83.8 ±2.04^{abc}	28.0±0.82^{c}
Anterior saddle 2	14.0±0.22^{bc}	20.4±0.40^{bcde}	13.6±0.21^{cd}	84.4 ±1.90^{bc}	28.1±0.81^{c}
Anterior saddle 1	14.6±0.20^{d}	21.5±0.39^{e}	14.3±0.20^{e}	81.4±1.48^{ab}	27.7±0.67^{c}
Central saddle 3	13.6±0.26^{ab}	19.3±0.44^{ab}	13.0±0.24^{abc}	82.6±1.77^{abc}	29.7±0.87^{cd}
Central saddle 2	13.9±0.18^{bc}	19.3±0.37^{ab}	13.4±0.16^{bcd}	81.4±2.15^{ab}	27.8±0.85^{c}
Central saddle 1	14.6±0.23^{d}	20.5±0.44^{bcde}	14.1±0.20^{e}	80.5±1.79^{ab}	24.8±0.82^{b}
Back saddle 3	13.6±0.25^{ab}	19.5±0.31^{abc}	13.0±0.23^{ab}	82.6±2.03^{abc}	31.6±0.87^{de}
Back saddle 2	14.0±0.21^{bc}	19.4±0.39^{ab}	13.5±0.18^{bcd}	78.2±1.67^{a}	32.9±1.23^{e}
Back saddle 1	14.3±0.20^{cd}	20.7±0.42^{de}	13.9±0.18^{de}	82.7±1.70^{abc}	27.5±0.88^{c}
A_Fl with neck	14.0±0.17	19.9±0.31	13.5±0.15	82.6±1.20	27.0±0.45
A_Fl w/out neck	14.0±0.18	19.9±0.31	13.5±0.15	82.6±1.20	27.7±0.48

Table 4. Appropriate site for sampling of five fibre characteristics (AFD, CVD, SF, FC and SL) of vicuña fibre with the ranking of sampling sites according to those with the highest correlation coefficient (*r*-Pearson, shown in brackets). Abbreviations: AS=Anterior saddle; CS=Central saddle; BS=Back saddle, and number indicating which site (see Figure 1).

Ranking according to *r*-Pearson	AFD (WN)[1]	AFD (EN)[2]	CVD (EN)[2]	SF (EN)[2]	FC (EN)[2]	SL (EN)[2]
First	CS3 (0.91)	CS3 (0.92)	BS2 (0.92)	CS3 (0.90)	AS3 (0.82)	CS1 (0.76)
Second	AS3 (0.90)	AS3 (0.91)	BS1 (0.85)	AS3 (0.89)	BS2 (0.77)	BS3 (0.71)
Third	BS2 (0.89)	BS3 (0.89)	CS2 (0.85)	BS3 (0.85)	BS3 (0.76)	AS2 (0.70)

[1]WN = Including the neck fibre; [2]EN = Excluding the neck fibre.

Table 5. Differences between the average of all fleece sampling sites, excluding the neck fibre, and the central saddle site 3 (CS3) for 5 fibre characteristics.

	AFD	CVD	SF	FC	SL
Average all the fleece	13.98	19.9	13.49	82.6	27.7
Average of CS3	13.59	19.3	13.04	82.6	29.7
Difference	0.39	0.6	0.45	0.0	-2.0
% of difference	2.8	2.9	3.3	0.0	-7.2
r-Pearson	0.92	0.84	0.90	0.74	0.58

textile use (McGregor, 2006) and marketing purposes. The explanation of the VR/R/F component, which is about half of the total variance for 3 of the 5 characteristics examined, would indicate that there are large relative variations between fibres and along of fibres within a sampling site. The variance component estimates are higher with respect to the variance component estimates of VAR/F and VAF for 4 of fibre characteristics examined.

Previous studies have shown that, in Merino sheep, the source of the greatest variation for AFD is the variance component among fibres within staples (64%) (Hansford, 1992). For this reason the CVD has importance in the selection of fibre producing animals and in evaluating the quality of their fleece. The low variation of AFD among body sites in Merino fleeces within fleeces (VAR/F = 4%, Hansford, 1992), contrasts with our finding with vicuñas, where VAR/F and VAF explain nearly 60% of the total variation. This contribution to total variance was greater than that reported for alpacas, sheep and Angora goat fleeces. The results of the present investigation also found that the VR/R/F contribution to total variance was relatively lower than the reports for alpacas, sheep and Angora goat fleeces. These differences in the variance component estimates for AFD are also similar for the other fibre characteristics examined in the present investigation such as SF and CVD, but not for FC.

The lower VAR/F reported for Merino sheep (Hansford, 1992) and Angora goats fleeces (Taddeo et al., 2000), would be due to the effect of the artificial selection of these animals that has been performed for a long period of time, in order to obtain a more homogeneous fleece. This selection would result in an increase in the relative contribution of VR/R/F. Many programs of fibre animal improvement have a criterion for the decrease in the CVD which is aimed to reduce the variation between fibres within fleeces. As the vicuñas are wild animals without artificial selection, they clearly maintain a high variability between the different parts of the fleece. Such variability may allow better protection against adverse climatic factors that could impinge with greater or lesser effect in different areas of the body of the animal, since the fibres of the fleece have an important role in the insulation of the animals to help maintain their homoeothermy. Moore et al. (2011), working on alpacas, found that fine fibres provide less insulation compared with coarser fibres, as their study showed that fleeces of fine fibres had a greater heat loss at higher wind speeds, resulting in a higher requirement of energy in order to maintain homeostasis.

In general, the AFD increases from the dorsal area to the flanks and finally to the extremities at vicuñas (Figure 2). Consequently, sections of the fleece near the sampling sites VA3, VC3 and VP3 (located approximately 10 cm below the dorsal line) have the highest quality fibre (finest fibres, with lower variation and greater curvature). Vicuña fleeces also show a clear trend of variation in fibre characteristics from the anterior area towards the posterior area, in agreement with findings for mohair (Taddeo et al., 2000; McGregor and Butler, 2008), alpacas (Aylan-Parker and McGregor, 2002; McGregor et al., 2012) Merino wool (Turner et al., 1953; Doney and Smith; 1961; Fish et al., 2002) and American bison wool (McGregor, 2012).

The range of AFD among fleece sampling sites of the vicuña did not exceed 1.5 µm. This indicates that it would be difficult to separate different fibre diameter qualities from within these vicuña fleeces, contrary to

Table 6. Linear regression models and coefficients of determination (r^2) to predict AFD, CVD, SF, FC and SL of the whole fleece, considering from one sampling site as independent variable.

Linear models to predict variables	r^2
$AFD = 5.558+0.620\ AFD_{CS3}$	0.85
$CVD = 0.055+0.743\ CVD_{BS2}$	0.84
$SF = 6.041+0.571\ SF_{CS3}$	0.90
$FC = 2.298+0.474\ FC_{AS3}$	0.67
$SL = 16.796+0.440\ SL_{CS1}$	0.58

the ease and need for such fibre separation in fleeces from alpacas (Aylan-Parker and McGregor, 2002) for better marketing. Clearly in the case of vicuña fleeces used in the present investigation it is not necessary for the classification of fleece according to body regions, at least with respect to characteristics such as AFD and CVD.

While it is true that the vicuña neck has fine fibres with shorter length, it is common practice not to harvest fibres from this body region as they are too short for typical woollen spinning systems. Recent reports suggest that there is textile technology to process 20 mm fibres, such as in the case of blending mixtures of cashmere and silk (Nibikora and Wang, 2010) or in processing cotton. It could be possible to harvest and sell short fibre from the vicuña neck, given that the price of the vicuña fibre ranges around $US 500/kg, and the value of the neck fibre (20 g) would be about $US 10.

This research suggests that the best area of sampling for predicting the AFD of the whole vicuña fleece is the site CS3, located at the level of the tenth rib and 10 cm from the dorsal line near the mid-back. This result differs slightly to that reported with sheep (Turner et al., 1953; Saddick, 1993), Angora goats (Taddeo et al., 2000) and alpacas fleeces (Aylan-Parker and McGregor, 2002), because in these species, the best sampling area is located at level of the 10th rib between the dorsal line and the ventral line (CS2, mid-side site). However, while site CS3 may be the best single site for the characterization of vicuñas fleeces for AFD, CVD, SF and FC, this site is not the best site for SL (Tables 5, 6).

It has been acknowledged for many years that the use of more than one site of sampling of the Merino fleece will improve the accuracy of estimates for the whole fleece (Turner et al., 1953). Clearly sampling more than one site would increase costs by additional testing and analysis, which would be expensive for vicuña producers. Therefore before taking decisions on the number of zones to sample it is advisable to evaluate economic, logistical and human aspects involved for vicuña fleece evaluation.

In conclusion, the results show that the vicuña fleece, in comparison with sheep, goats and alpacas fleeces, has greater variability among sampling sites across the fleece, but a smaller variability among fibres within sampling sites and along the fibre. Also, the vicuña fleece is more homogeneous than the sheep, mohair and alpaca fleece. For the purposes of classification of vicuña each fleece is likely to be considered within a single fibre diameter quality, as opposed to alpacas, Merino and Angora goats, whose fleeces need to be separated into several fibre diameter qualities. Finally, we found the sampling site CS3 near the mid-back to have the highest correlation with the average of the important fibre quality characteristics across the whole fleece.

Acknowledgments

Foundation BBVA is thanked for providing financial support of the project CAMELSIMP. Mr. Paul Mayhua, students of Husbandry Professional School, and workers of CIPCS Lachocc of UNH are thanked for field support. Regional Government of Huancavelica is thanked for permission to collect data. Dr. Bruce McGregor, Deakin University, Australia is also thanked for English revision and for helpful comments.

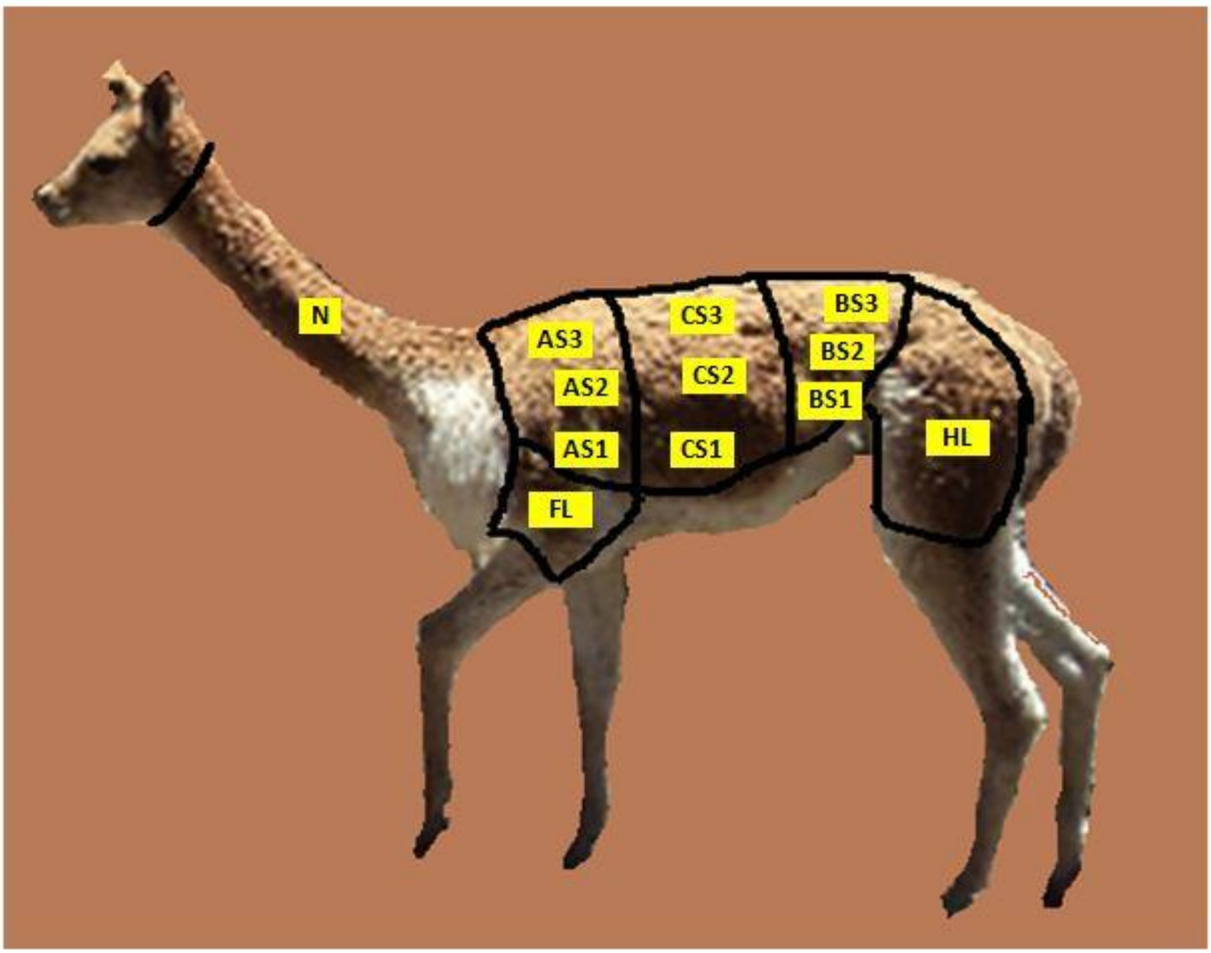

Figure 1. Location of vicuña sampling sites sampled (AS=anterior saddle; CS=central saddle; BS=back saddle; N= neck; FL= forelimb; HL= hindlimb).

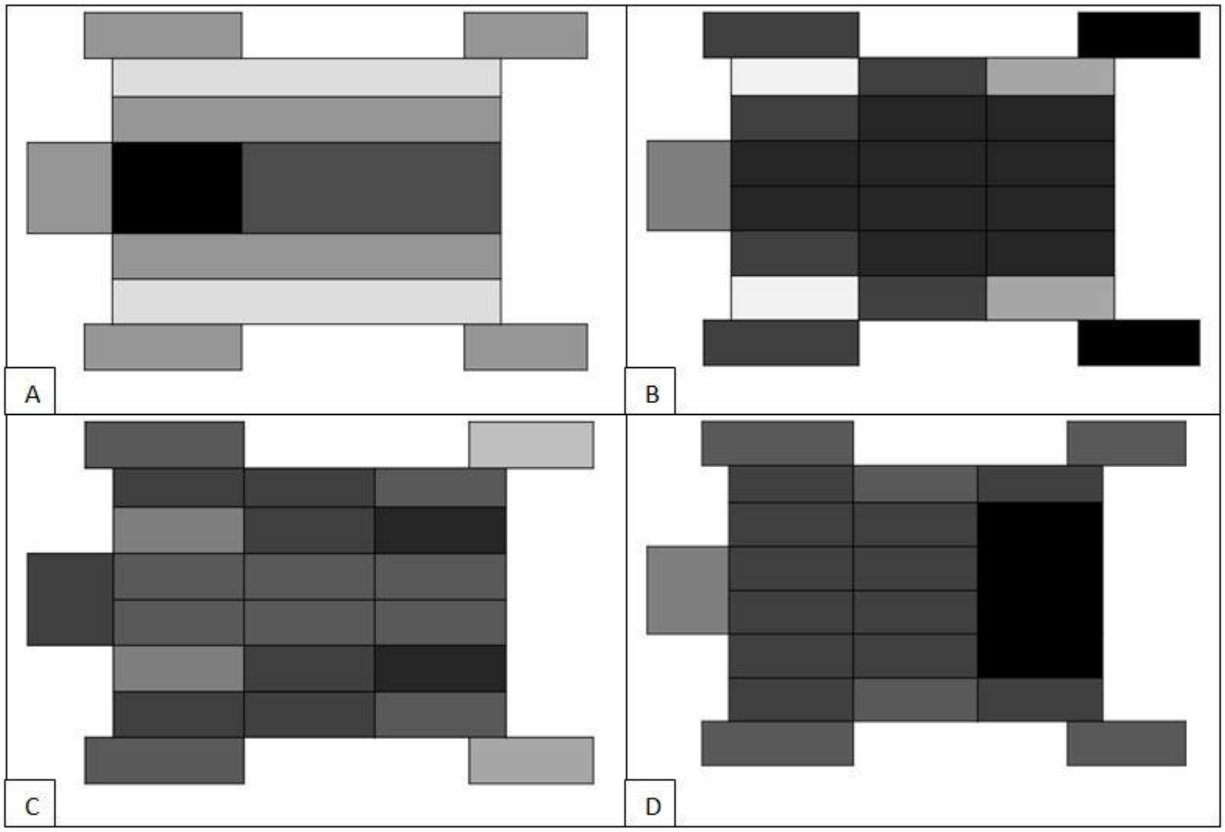

Figure 2. Spectra for vicuña fleece showing top variations by body areas. (A) Darkest and lightest zones produce fines and thicker fibres, respectively, (B) Darkest and lightest zones have fibre with less and more CVD, (C) In darker zones are located fibres with the highest fibre curvature, contrary to the lighter zones, and (D) At darkest areas are located fibre with larger staple length. (It was prepared on the basis of means tests, Table 3).

References

Aylan-Parker J., McGregor B.A., 2002. Optimising sampling techniques and estimating sampling variance of fleece quality attributes in alpacas. Small Rumin. Res., 44: 53-64.

Bonacic C., 2005. Vicuña ecology and management. The Camelid Quarterly, 75-95.

Brims M.A., Peterson A.D., Gherardi S.G., 1999. Introducing the OFDA2000 – For rapid measurement of diameter profile on greasy wool staples. IWTO, Raw Wool Group Report RWG04, Florence, Italy.

Carpio M., 1991. La fibra de camélidos. In: C. Novoa and A. Flores (Eds). Producción de rumiantes menores: Alpacas. Lima: RERUMEN, 297-359.

Cardelino R.C., Mueller J.P., 2009. Fibre production and sheep breeding in South American. Proc. Assoc. Advmt. Anim. Breed. Genet., 18: 366-373.

Chapman R.E., Young S.S.Y., 1957. Study of wool production per unit area of skin Australian Merino sheep. Aust. J. Agric. Res., 8: 723-732.

Doney J.M., Smith S.F., 1961. The fleece of the Scottish Blackface sheep. II. Variation in the fleece components over the body of the sheep. J. Agric. Sci., 56: 375-378.

Hansford K., 1992. Fibre Diameter Distribution: Implication for Wool Production. Wool Tech. Sheep Breed., 40(1): 2-9.

Fish V.E., Mahar T.J., Crook, B.J., 2002. Sampling variation over a fleece for mean fibre diameter, standard deviation of fibre diameter and mean fibre curvature. Wool Tech. Sheep Breed., 50: 798-804.

Kuehl R.O., 2000. Design of Experiments: Statistical Principles of Research Design and Analysis. Second Edition. Brooks/Cole Cengage Learning. Belmont, USA.

Manso C., 2011. Determinación de la calidad de fibra de alpaca en Huancavelica (Perú): Validación de los métodos de muestreo (Determination of alpaca fibre quality in Huancavelica: Validation of sampling methods.). Thesis in Agrarian Production. Universidad Pública de Navarra. Spain.

Moore K.E., Blache D., Maloney S.K., 2011. Fibre diameter and insulation in alpacas: The biophysical implications. Small Rumin. Res., 96: 165-172.

McGregor, B.A., 2006. Production, attributes and relative value of alpaca fleeces in southern Australia and implications for industry development. Small Rumin. Res., 61: 93-111.

McGregor, B.A., 2012. Production, properties and processing of American bison (Bison bison) wool grown in southern Australia. Anim. Prod. Sci., 57: 431-435.

McGregor, B.A., 2014. Variation in the softness and fibre curvature of cashmere, alpaca, mohair and other rare animal fibres. J. Textile Inst.in press, doi:10.1080/00405000.2013.828448

McGregor B.A., Butler K.L., 2008. Variation of mean fibre diameter across mohair fleeces: Implications for within flock animal selection, genetic selection, fleece classing and objective sale lot building. Small Rumin. Res., 75: 54-64.

McGregor B.A., Ramos H., Quispe, E.C., 2012. Variation of fibre characteristics among sampling sites for Huacaya alpaca fleeces from the High Andes. Small Rumin. Res., 102: 191-196.

Newman S.N., Paterson D.J., 1996. Variation in fleece characteristics over the body of alpacas. Proc. New Zealand Soc. Anim. Prod., 56: 338-341.

Newman S.N., Paterson D.J., 1999. Variation in fibre and fleece characteristics between and within South African, New Zealand, and South African x New Zealand Angora goat genotypes. New Zealand J. Agric. Res., 42: 77-82.

Nibikora I., Wang J., 2010. Optimum Selection of the Openning roller and Navel for rotor Spun Silk/Cashmere Blended Yarn. Fibres & Text., 18(5): 35-38.

Qu L., Guennel T., Marshall S.L. 2013. Linear Score Tests for Variance Components in Linear Mixed Models and Applications to Genetic Association Studies. Biometrics, 89(4): 883-892.

Quispe E.C., Rodríguez T.C., Iñiguez L.R., Mueller J.P., 2009. Producción de fibra de alpaca, llama, vicuña y guanaco en Sudamérica (Production of alpaca, llama, vicuña and guanaco fibre in South America). Anim. Genet. Res. Inform., 45: 1 14.

Quispe E.C., Ramos H., Mayhua P., Alfonso L., 2010. Fibre characteristics of vicuña (Vicugna vicugna mensalis). Small Rumin. Res., 93(1): 64-66.

Saddick I.M., 1993. Variation in some wool characteristics over the body of Ossimi sheep. Menofiya J. Agric. Res., 18: 1143-1155.

Sarno R.J., Villalba L., Bonacic C., González B., Zapata B., MacDonald D.W., O'Brien S.J., Jonson W.E., 2003. Phylogeography and subspecies assessment of vicuñas in Chile and Bolivia utilizing mtDNA and microsatellite markers: implication for vicuña conservation and management. Conserv. Genet., 80: 1 14.

Tabbaa M.J., Al-Azzawi W.A., Campbell D., 2001. Variation in fleece characteristics of Awassi sheep at different ages. Small Rumin. Res., 41: 95-100.

Taddeo H.R., Duga L., Almeida D., Willems P., Somlo R., 2000. Variation of mohair quality over the body in Angora goats. Small Rumin. Res., 36: 285-291.

Turner H.N., Hayman R.H., Riches J.H., Roberts N.F., Wilson L.T., 1953. Physical definition of sheep and their fleece for breeding and husbandry studies with particular reference to Merino sheep. CSIRO Divisional Report No 4, 1953.

Vilá B., 2002. La silvestría de las vicuñas, una característica esencial para su conservación y manejo (The wildlife of vicuñas, essential characteristic for its conservation and management). Ecolog. Austral., 12: 79-82.

Watkins P., Buxton A., 1992. Luxury Fibres. The Economist Intelligence Unit Special Report No. 2633. Business International, London, UK.

Wheeler J., 1995. Evolution and present situation of the South American Camelidae. Biol. J. Linnean Soc., 54: 271-295.

Yacobaccio H.D., 2006. Variables morfométricas de vicuñas (Vicugna vicugna vicugna) en Cieneguillas, Jujuy (Morphometrics variables of vicuñas in Cieneguillas, Jujuy). In: Investigación, conservación y manejo en vicuñas. B. Vilá B. (Eds). Proyecto MACSArgentina, Buenos Aires (Argentina), 101-112.