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Optimising sampling techniques and estimating sampling variance of fleece quality attributes in alpacas

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Abstract

Huacaya and Suri alpacas ($n = 120$) of varying age, live weight (LWT) and sex (female, male) were selected randomly from four farms in southern Australia. At shearing, fleeces were divided into four components: saddle (S), neck (N), pieces (P; front and back legs, belly, apron) and the midside sample (MS). Components were weighed, sampled using the grid sampling technique and fleece attributes measured: clean washing yield (CWY), mean fibre diameter (MFD), coefficient of variation of the MFD (CV(D)), incidence of medullated fibres (Med), mean medullated fibre diameter (MedMFD) and coefficient of variation of the MedMFD (MedCV(D)). The MS and saddle grid sample (SGS) were used to create models to predict the fleece attribute of the total fleece (TF), saddle and neck fibre. For each fleece attribute MS had lower values than SGS and TF ($P < 0.005$) and SGS, except for CWY, had lower values than the P and TF ($P < 0.005$). The means were: MFD MS 27.5 μm, S 28.8 μm, N 28.7 μm, P 37.6 μm, TF 31.2 μm; CV(D) MS 24.3%, S 27.0%, N 28.6%, P 30.6%, TF 28.1%; CWY MS 90.2%, S 91.4%, N 88.9%, P 92.8%; Med 24.4%, S 33.1%, P 44.5%, TF 35.2%; MedMFD MS 32.7 μm, S 34.4 μm, P 41.1 μm, TF 36.0 μm; MedCV(D) MS 19.4%, S 22.3%, P 25.9%, TF 23.4%. The MS was found to be an appropriate sample from which to predict the MFD and CWY. CV(D) was only satisfactorily predicted by the SGS ($r = 0.88$), with the exception of the neck fleece, for which neither the MS nor SGS could provide an accurate predictive model. The MS did not sufficiently account for the variation in Med ($r = 0.73$–0.79). The SGS gave accurate prediction of Med ($r = 0.98$). Sex effects were detected in models for TFMFD, NMFD and TFCV(D). LWT effects were detected in models for NMFD, NCV(D) and TFMedMFD. SGS often gave a more accurate prediction of a fleece attribute but it requires the removal of the entire fleece, whereas MS can be removed by shearing a small area or can be removed during shearing with a minimum of effort. Sampling variance for SGS was generally two to four times greater than the sampling variance for MS with the 95% confidence limits (CLs) for SGS being about double those of MS for most parameters except for clean washing yield (CWY) which were similar. Sampling variance for the incidence of medullated fibres in SGS was very high. The large 95% CL for all the tested fibre attributes indicate that alpaca breeders and advisors need to consider taking suitable duplicate measurements and other precautions during breeding and animal selling programs.

Keywords: Fibre diameter; Coefficient of variation; Medullated fibre; Sampling; Alpaca selection; Alpaca fibre marketing

1. Introduction

In Australia, fibre production from alpacas began in the 19th century, but the industry failed to establish. In the 1980s, alpacas were imported from Chile and more

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recently from Peru. Alpacas have since been exported to the United States of America, Canada, and Europe from Australia. Archaeological findings in Peru, from about 1000 years ago, have demonstrated that alpacas were bred under strict control. The fibre was much finer than in present day animals with an average diameter of about 17.9 μm and a S.D. of only 1.0 μm. Medullation of the fibre was also very low and alpaca fibre was crimped and lustrous (Wheeler et al., 1992).

Peruvian and Chilean farmers now keep alpacas (*Lama pacos*) and llamas (*Lama glama*) for their fibre, meat and transportation and often graze their animals mixed with sheep. Farming methods (particularly in Chile) are primitive and in many regions there has been little progress in genetically improving stock. Alpacas have been cross-bred with llamas over time because the farmers wanted a more robust multi-purpose animal. The llamas produce more meat because of their greater body size, but they have a much coarser fibre than the alpaca. Llama characteristics, such as coarse medullated fibre can be seen in many South American 'alpacas' today. Consequently, alpacas entering Australia and other countries have been of variable quality.

While alpaca breeders in Australia, USA, Canada and the United Kingdom have the potential to improve fleece quality by genetic selection, breeders must know what characteristics to improve and they must be able to accurately measure them. Since 1947, an accepted method for testing sheep wool has been to take a midside sample (MS) (Turner et al., 1953). The MS has been used to test characteristics of importance such as fibre diameter, fibre population, staple length, density of fibres per unit area and staple crimp (Turner et al., 1953). The MS in sheep is located over the third last rib, half-way between the mid-line of the belly and the mid-line of the back (Fig. 1). The theory in sheep behind using a MS sample is that a MS sample test result (based on minicoring or testing after carding) is close to the mean of both dorso–ventral and anterio–posterior attribute variation. An initial assumption can be made that the same theory may apply to alpacas. The MS is a very convenient site to use because it can be easily shorn without removing the entire fleece.

Nearly 40 years after the publication of Turner et al. (1953), Fleet et al. (1993) found that, although the MS was highly correlated with the mean fibre diameter (MFD) of wool top (wool processed up to the spinning stage), the MS was finer and the differences were not consistent, suggesting the MS is not a reliable predictive tool for the diameter of top. Some of the differences reported by Fleet et al. (1993), may be due to the effect of fibre breakage and subsequent loss during carding and noil removal (combing). Stadler and Gillies (1994) found that in Merinos, the MS MFD actually tested finer than the average for the whole fleece, particularly for the finer animals in the population. It was suggested this was due to intense selection over the years for finer fleece based on the MS rather than selection for a finer entire fleece.

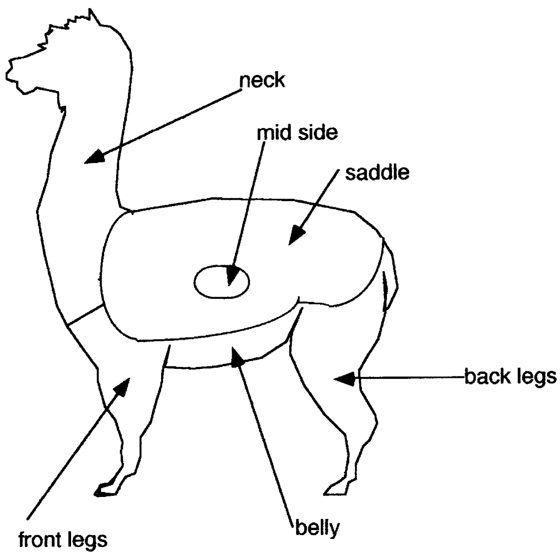

Fig. 1. Location of the midside sampling site, the saddle, neck and fleece components that form the pieces (front legs including apron, belly and back legs) in alpacas.

Prior to these reports, Butler et al. (1991) found that top produced from Merino wool was better predicted by a grid sampling technique than by a MS. The grid sampling technique involves laying out the fleece that has to be tested on a flat surface, and taking 20 random grab samples over the entire fleece. The grid sample can detect variations in the fleece that the MS does not detect. Grid sampling in this way avoids destroying the staple length of an entire commercial fleece, which would happen if a fleece was core sampled.

The grid sampling technique has been suggested as the best method for taking samples from cashmere producing goats for measuring attributes, such as yield of commercially useable cashmere and cashmere MFD (McGregor, 1994). This research showed that cashmere yield was overestimated by the MS sample and the MS tended to underestimate the diameter of the cashmere.

In mohair, Gifford (1989) reported that the MS site was the most appropriate sampling site when assessing the fibre diameter, incidence of medullated fibres, staple length and clean washing yield compared with eight other defined sites. A subsequent New Zealand study (Wuliji et al., 1992, 2000) concluded that the MS site was the most appropriate site to measure MFD but no grid sampling or core sampling techniques were tried, no other fleece attributes were measured and statistical analyses were limited. Sampling the entire fleece of Angora goats to detect the occurrence of medullated fibres in fine mohair is better than sampling only the MS site, as medullation varies considerably over the fleece (Gifford, 1989; Taddeo et al., 2000). Medullated fibres are regarded as an undesirable characteristic as they tend to be of higher diameter, brittle, and they diffract light differently following dyeing causing uniformity of color problems (Hunter, 1993).

As grid sampling has been shown to be important in both less improved breeds, such as cashmere goats and in improved breeds, such as Australian Merino sheep, and as the accuracy of grid sampling has not been previously assessed in alpacas, this study was designed to test the accuracy of the grid sampling and MS techniques for estimating a range of alpaca fleece quality attributes. The project was associated with a larger scale survey of the fibre quality of alpacas in Australia (Tuckwell et al., 1995; McGregor, 1997; McGregor et al., 1997).

2. Materials and methods

2.1. Source of animals

Male and female Huacaya and Suri alpacas ($n = 120$) of varying age and live weight (LWT) were selected randomly from four collaborating farms in southern Australia. The properties were located in: Penola, South Australia and Camperdown, Creswick, and East Trentham, Victoria, Australia.

2.2. Methods of sampling

2.2.1. Sites

Three sampling methods used were:

1. MS, the sample site, centred over the 10th rib midway between the back line and belly line (Fig. 1.), was carefully located and marked with a scourable coloured spray, immediately prior to the alpaca being shorn. Once the fleece was shorn from the midside region, the MS weighing about 50 g, was taken from the sprayed part of the fleece. The sample was then weighed to the nearest gram, identified with a numbered card and placed into a plastic bag that was sealed.
2. Saddle grid sample (SGS), when shearing was completed, the saddle (S) was weighed to the nearest gram and then laid out covering a 3 m^2 table to a uniform thickness. Samples representing this entire area of the fleece were then drawn from the saddle in a random fashion ($n = 30$). The SGS weighed about 50 g and several further random draws were taken if the sample weighed less than 50 g. The sample was then identified and bagged as described for MS.
3. Fleece component grid sample, the procedure used for SGS was undertaken for the other components of the fleece. These components were the neck (N) and pieces (P). According to standard industry practice, the pieces consisted of the fibre shorn from the belly, head, back legs, front legs, apron (area between front legs and neck) and floor sweepings (locks) (Fig. 1). The neck and pieces components were separately weighed. Note that only 43 alpacas had neck samples taken separately, due to the difficulties encountered obtaining the specified samples in some of the shearing sheds. When necks were not separately sampled they formed part of the pieces component.

2.2.2. Sampling methods for components of sampling variation

To estimate the subsampling variance for MS and SGS, additional samples were taken as follows:

1. For the MS, another MS was taken on the opposite side of the animal at the time of shearing and weighed and bagged separately.

2. For the SGS, following the first random grid sampling, a second random grid sample was taken in the same manner and then weighed and bagged separately.

2.3. Measurements

The samples were taken to the Fibre Testing Service, Fibre Quality Department, Department of Natural Resources and Environment, Victorian Institute of Animal Science. From each fleece component sample, a random subsample of 20 g was placed into a CSIRO mini corer which was used to remove seven cores each of 2 mm diameter. Several coring operations were completed to remove at least 150 mg of fibre ''snippets''. The snippets were then given an aqueous scouring, gently dried and placed into an air conditioned room for 24 h ($65 \pm 2\%$ RH and 20 ± 2 °C) prior to measurement on the OFDA (optical fibre diameter analyser) (Baxter et al., 1992; IWTO-47-95, 1995; Peterson and Gherardi, 1996). The OFDA was calibrated using standard wool tops and set to measure 6000 snippets. For each sample, two separate OFDA measurements were made and the results were analysed. The OFDA measurements recorded were: MFD, standard deviation of the MFD (S.D.), coefficient of variation of the MFD (CV(D)), incidence of medullated fibres (Med, percent by number and by weight), MFD of medullated fibres (MedMFD), S.D. of MedMFD (MedSD), coefficient of variation of MedMFD (MedCV(D)) (see Appendix A).

Following the minicoring of the sample, the remaining sample was used to estimate the CWY of greasy sample (IWTO-33-88; modified using duplicate 20 g samples and a moisture regain of 16%).

The OFDA uses a measurement of opacity to predict the proportion and weight of medullated fibres. When a fibre is hollow (medullated), it causes dispersion and reflection of light and it appears more opaque than a solid standard fibre. When a fibre exceeds the threshold opacity level, it is registered as medullated. Dark fibres also absorb large portions of the light and can be registered mistakenly as medullated. Consequently, only fleeces visually classified as white and pale or light fawn were measured for medullated fibres ($n = 45$).

2.4. Statistical analyses

2.4.1. Fleece attributes

Total fleece (TF) greasy weight (TFgwt) harvested from each animal was calculated as the sum of the greasy fleece components weighed from each animal. The clean fleece weight (cwt) for each fleece component was calculated as: cwt = gwt × CWY. Weighted means for the TF were calculated for a range of fleece attributes as:

1. $\mathrm{TFcwt} = \mathrm{Scwt} + \mathrm{Pcwt} + \mathrm{Ncwt} + \mathrm{MScwt}$
2. $\mathrm{TFMFD} = ((\mathrm{NMFD} \times \mathrm{Ncwt}) + (\mathrm{SMFD} \times \mathrm{Scwt}) + (\mathrm{PMFD} \times \mathrm{Pcwt}) + (\mathrm{MSMFD} \times \mathrm{MScwt}))/\mathrm{TFcwt}$
3. $\mathrm{TFSD} = ((\mathrm{NSD} \times \mathrm{Ncwt}) + (\mathrm{SSD} \times \mathrm{Scwt}) + (\mathrm{PSD} \times \mathrm{Pcwt}) + (\mathrm{MSSD} \times \mathrm{MScwt}))/\mathrm{TFcwt}$
4. $\mathrm{TFCV(D)} = (\mathrm{TFSD}/\mathrm{TFMFD}) \times 100$
5. $\mathrm{TFMed} = ((\mathrm{NMed} \times \mathrm{Ncwt}) + (\mathrm{SMed} \times \mathrm{Scwt}) + (\mathrm{PMed} \times \mathrm{Pcwt}) + (\mathrm{MSMed} \times \mathrm{MScwt}))/\mathrm{TFcwt}$
6. $\mathrm{TFMedMFD} = ((\mathrm{NMedMFD} \times \mathrm{Ncwt}) + (\mathrm{SMedMFD} \times \mathrm{Scwt}) + (\mathrm{PMedMFD} \times \mathrm{Pcwt}) + (\mathrm{MSMedMFD} \times \mathrm{MScwt}))/\mathrm{TFcwt}$
7. $\mathrm{TFMedSD} = ((\mathrm{NMedSD} \times \mathrm{Ncwt}) + (\mathrm{SMedSD} \times \mathrm{Scwt}) + (\mathrm{PMedSD} \times \mathrm{Pcwt}) + (\mathrm{MSMedSD} \times \mathrm{MScwt}))/\mathrm{TFcwt}$
8. $\mathrm{TFMedCV(D)} = \mathrm{TFMedSD}/\mathrm{TFMedMFD}$

Fleece attributes from each sample site (MS, S, N, P) and the calculated values for the TF were compared using a paired *t*-test (Anon., 1998). Regression analyses were performed using Genstat 5 (Anon., 1998) and non-significant variables were progressively removed from the model. No curvilinear models were significant. The multiple linear models were of the form:

$$y = ax + b + c(\text{variable 1}) + d(\text{variable 2}) + \cdots$$

where y is the fleece component being predicted and x the attribute measured on the SGS or MS. Other variables included: breed (Huacaya = 0, Suri = 1); sex (female = 0, male = 1); property (0–3); LWT (kg); age (years).

The models compared fleece measurements obtained on the midside site and on the saddle with measurements obtained on other fleece components and with the calculated values for the TF.

The comparisons were: MS versus S; MS versus TF; S versus TF; MS versus N; S versus N.

A full list of measurements, their definition and abbreviations are shown in Appendix A.

2.4.2. Estimated sampling variance and 95% confidence limits of fleece testing

Duplicate MS and SGS were taken from half of the fleeces in the study ($n = 58$).

Sampling variance was calculated as: $s^2 = \Sigma$ (differences between test results)$^2/2(n-1)$.

Confidence limits were calculated as: 95% CL $= \sqrt{(s^2 \times 1.96)}$.

3. Results

The mean, maximum and minimum values obtained for all fleece attribute measurements and calculated values are shown in Table 1. The mean values of all fleece attributes measured from SGS were lower than the calculated values for the TF ($P < 0.001$, Table 1).

3.1. Mean fibre diameter

The MSMFD was 1.2 μm finer than SMFD and NMFD, 3.7 μm finer than TFMFD and 10.1 μm finer than PMFD ($P < 0.005$). SGSMFD was 2.4 μm finer than TFMFD and 8.8 μm finer than PMFD ($P < 0.005$, Table 1).

The MSMFD and SGSMFD were highly correlated ($r = 0.89$, Table 2) with the final model accounting for 79% of the variation in SGSMFD with the slope approximately 1. TFMFD was also highly correlated with the MSMFD with a slope of 1 and the final model accounted for 82% of the variation. Sex was significant ($P < 0.05$) in the final model with fleeces from males being 1.3 μm coarser than fleeces from females. TFMFD was more highly correlated with SGSMFD. The final model, with the inclusion of sex, accounted for 91% of the variation in TFMFD. NMFD was predicted better by the model with SGSMFD than with MSMFD and age was a significant term ($P < 0.05$, Table 2).

3.2. Mean fibre diameter coefficient of variation

The MSCV(D) was 2.7% lower than SGSCV(D), 3.8% lower than TFCV(D) and 4.3% lower than NCV(D) ($P < 0.005$). Models predicting CV(D) of SGS and TF were moderately correlated ($r = 0.65$–0.70) with MSCV(D) and SGSCV(D) (Table 3). In contrast, the TFCV(D) was more highly correlated with the SGSCV(D) ($r = 0.88$). Sex had a small, but

Table 1
Mean, S.D. and ranges in measured and derived variables of alpaca fleece

Variable	Mean	S.D.	Minimum	Maximum
Age (years)	3.7	2.3	0.3	7.9
Live weight (kg)	66.9	16.5	29.9	110.8
Weight of fibre (kg)				
Saddle	2.01	1.26	0.33	5.69
Neck[a]	0.74[a]	0.27	0.14	0.93
Pieces	0.86	0.62	0.11	4.54
Total fleece weight	3.13	1.51	0.47	9.25
Mean fibre diameter (μm)				
MS[b]	27.5 a	4.6	19.9	41.0
Saddle	28.8 b	4.9	19.4	42.3
Neck	28.7 b	6.4	20.6	45.8
Pieces	37.6 d	6.9	21.8	57.6
Total fleece	31.2 c	5.3	20.0	44.9
Mean fibre diameter coefficient of variation (CV(D), %)				
MS	24.3 a	4.0	16.3	35.2
Saddle	27.0 b	3.5	18.4	35.4
Neck	28.6 b	4.3	20.9	37.8
Pieces	30.6 d	4.2	23.0	43.8
Total fleece	28.1 c	3.3	21.4	36.5
Clean washing yield (%)				
MS	90.2 a	3.6	78.0	98.0
Saddle	91.4 b	3.4	79.9	99.6
Neck	88.9 a	2.7	82.6	92.8
Pieces	92.8 b	2.7	86.9	99.6
Incidence of medullated fibre (%)				
MS	24.4 a	17.1	1.5	73.3
Saddle	33.1 b	19.8	1.2	75.0
Pieces	44.5 d	21.6	6.2	85.5
Total fleece	35.2 c	19.9	3.6	75.2
Mean medullated fibre diameter (μm)				
MS	32.7 a	2.6	26.0	38.6
Saddle	34.4 b	3.5	29.0	43.0
Pieces	41.1 d	5.0	31.0	51.0
Total fleece	36.0 c	3.6	27.9	44.1
Mean medullated fibre diameter coefficient of variation (CV(D), %)				
MS	19.4 a	3.1	13.8	27.1
Saddle	22.3 b	3.8	16.6	35.8
Pieces	25.9 d	3.6	19.5	35.7
Total fleece	23.4 c	3.1	18.7	32.7

Within variables, mean sampling site values with a different letter are significantly different at $P < 0.005$.

[a] Not all fleeces had necks measured.

[b] MS: midside site.

Table 2
Regression models for the prediction of MFD (μm) of fleece components from either MS or SGS

Dependent variable	Constant (±S.E.)	Regression constant	Independent variable	r	R^2	R.S.D.
SGSMFD	3.26 ± 1.28	0.92 ± 0.05	MSMFD	0.89	79	2.2
TFMFD	2.70 ± 1.33	1.01 ± 0.04	MSMFD		81	
		1.26 ± 0.54	+Sex	0.90	82	2.2
TFMFD	0.74 ± 0.96[a]	1.05 ± 0.03	SGSMFD		90	
		1.42 ± 0.38	+Sex	0.95	91	1.6
NMFD	−5.70 ± 2.44	1.06 ± 0.09	MSMFD		80	
		1.80 ± 0.87	+Sex			
		0.07 ± 0.03	+LWT	0.91	83	2.6
NMFD	−3.05 ± 1.90	1.05 ± 0.07	SGSMFD		84	
		0.73 ± 0.15	+Age	0.95	90	2.1

[a] Indicates the constant was not significant ($P > 0.05$). All remaining values significant at $P < 0.05$.

significant effect on the model ($P < 0.05$) indicating that males had, on average, fleeces with a TFCV(D) 1% higher than fleeces of females. NCV(D) was poorly correlated with MSCV(D) and SGSCV(D). However, LWT was significant in both models ($P < 0.05$), accounting for an additional 7–11% of the variation.

3.3. Clean washing yield

CWY estimates for the MS and neck were lower than the CWY estimates for the saddle and pieces ($P < 0.005$, Table 1) and were very highly correlated with fleece components (Table 4). The saddle cwt was well predicted by using the MSCWY (Table 4). TFcwt and Ncwt were equally well predicted by the MSCWY and SCWY (Table 4).

3.4. Incidence of medullated fibres

The incidence of medullated fibres by number, in the MS was 8.7% less than in the saddle, 10.8% less than in the TF and 20.1% less than in the pieces ($P < 0.005$, Table 1). While TFMed and SGSMed were moderately correlated with MSMed ($r > 0.7$), with slopes no different from 1, the R.S.D. for these models were particularly high (R.S.D. > 12%, Table 5), indicating the difficulty in predicting these measures. The TFMed was very highly correlated with SGSMed ($r = 0.98$). The relationships between the incidence of medullated fibres by weight from different sites were similar to the incidence of medullated fibres by number and are not shown.

Table 3
Regression models for the prediction of MFD coefficient of variation (CV(D), %) of fleece components from either MS or SGS

Dependent variable	Constant (±S.E.)	Regression constant	Independent variable	r	R^2	R.S.D.
SGSCV(D)	11.9 ± 1.46	0.62 + 0.06	MSCV(D)	0.70	48	2.5
TFCV(D)	15.2 ± 1.44	0.54 ± 0.06	MSCV(D)	0.65	43	2.5
TFCV(D)	5.97 ± 1.17	0.82 ± 0.04	SGSCV(D)		75	
		0.99 ± 0.35	+Sex	0.88	77	1.6
NCV(D)	22.2 ± 4.38	0.50 ± 0.14	MSCV(D)		31	
		−0.09 ± 0.03	+LWT	0.63	40	3.3
NCV(D)	17.7 ± 6.6	0.58 ± 0.18	SGSCV(D)		30	
		−0.08 ± 0.03	+LWT	0.61	37	3.4

All values significant at $P < 0.05$.

Table 4
Regression models for the prediction of cwt (kg) of fleece components from either MS or SGS CWY

Dependent variable	Constant (±S.E.)	Regression constant	Independent variable	r	R^2	R.S.D.
Scfw	0.011 ± 0.012	1.06 ± 0.01	MSCWY	0.99	99	0.07
TFcfw	−0.33 ± 0.08	1.06 ± 0.03	MSCWY	0.97	94	0.37
TFcfw	−0.37 ± 0.08	1.06 ± 0.03	SGSCWY	0.97	94	0.36
Ncfwt	−0.008 ± 0.006[a]	1.02 ± 0.01	MSCWY	0.99	99	0.01
Ncfwt	−0.005 ± 0.006[a]	1.03 ± 0.02	SGSCWY	0.99	99	0.01

The independent variable was calculated by multiplying the CWY of independent variable with the greasy fleece weight of the dependent variable.

[a] Indicates the constant was not significant ($P > 0.05$). All remaining values significant at $P < 0.05$.

Table 5
Regression models for the prediction of the incidence of medullated fibres (Med, %) of fleece components from either MS or SGS

Dependent variable	Constant (±S.E.)	Regression constant	Independent variable	r	R^2	R.S.D.
SGSMed	8.1 ± 5.6[a]	1.09 ± 0.23	MSMed	0.73	53	13
TFMed	10.4 ± 5.0	1.15 ± 0.21	MSMed	0.79	62	12
TFMed	5.02 ± 1.7	0.97 ± 0.05	SGSMed	0.98	95	4

[a] Indicates the constant was not significant ($P > 0.05$). All remaining values significant at $P < 0.05$.

3.5. Medullated fibres mean fibre diameter

The MFD of medullated fibres in the MS was 1.7 μm finer than in the saddle, 3.3 μm finer than the TF and 8.4 μm finer than in the pieces ($P < 0.005$, Table 1). The saddle MedMFD was 1.6 μm finer than the TF and 6.7 μm finer than pieces MedMFD.

SGSMedMFD and TFMedMFD were poorly correlated with MSMedMFD ($r = 0.4-0.6$), with models accounting for less than half of the variation in MFD of medullated fibres (Table 6). LWT was also significant ($P < 0.05$) in the prediction of TFMedMFD. SGSMedMFD was highly correlated ($r = 0.93$) with TFMedMFD and LWT made a small but significant ($P < 0.05$) improvement in the model.

3.6. Medullated fibres mean fibre diameter coefficient of variation

MedCV(D) of the MS was 2.9% less than that of the saddle, and 6.5% less than the pieces ($P < 0.005$, Table 1). SGSMedCV(D) and TFMedCV(D) were

Table 6
Regression models for the prediction of MFD of medullated fibres (MedMFD, μm) and for the coefficient of variation of fibre diameter of medullated fibres (MedCV(D), %) of fleece components from either MS or SGS

Dependent variable	Constant (±S.E.)	Regression constant	Independent variable	r	R^2	R.S.D.
SGSMedMFD	14.9 ± 8.8[a]	0.60 ± 0.26	MSMedMFD	0.41	17	3.3
TFMedMFD	15.7 ± 6.7	0.41 ± 0.22	MSMedMFD		23	
		0.10 ± 0.04	+LWT	0.64	41	2.5
TFMedMFD	7.4 ± 2.6	0.73 ± 0.08	SGSMedMFD		82	
		0.05 ± 0.02	+LWT	0.93	87	1.2
SGSMedCV(D)	7.3 ± 6.2[a]	0.80 ± 0.30	MSMedCV(D)	0.48	23	4.2
TFMedCV(D)	12.6 ± 4.9	0.57 ± 0.24	MSMedCV(D)	0.44	19	3.3
TFMedCV(D)	6.7 ± 0.9	0.74 ± 0.04	SGSMedCV(D)	0.98	95	0.8

[a] Indicates the constant was not significant ($P > 0.05$). All remaining values significant at $P < 0.05$.

Table 7
Sampling variance and 95% CLs for fibre attributes measured from MS or SGS in alpacas

Fleece attribute	Midside sampling		Saddle grid sampling	
	Variance (s^2)	95% CLs	Variance (s^2)	95% CLs
MFD	0.7	1.6	3.6	3.7
S.D.	0.1	0.8	0.7	1.6
CV(D)	1.4	2.3	3.4	3.6
Med	12.2	6.9	74.8	16.9
Medwt	8.3	5.7	95	19.1
MedMFD	1.1	2.0	3.8	3.8
MedSD	0.4	1.3	0.7	1.6
CWY	4.4	4.1	6.0	4.8

poorly correlated ($r < 0.5$) with MSMedCV(D) (Table 6). However, TFMedCV(D) was highly correlated with SGSMedCV(D) ($r = 0.98$, Table 6).

3.7. Sampling variance and 95% confidence limits

Sampling variance for SGS was generally two to four times greater than the sampling variance for MS with the 95% CLs for SGS being about double those of MS for most parameters (Table 7) except for CWY which were similar. Sampling variance for the incidence of medullated fibres in SGS were very high. The 95% CL for MFD of SGS was affected by one outlier, which when removed reduced the 95% CL to 2.8 μm.

4. Discussion

A cross section of the base breeding alpaca population in southern Australia was obtained by sampling different sexes, breeds and properties with a wide variation in LWT (30–111 kg) and age (0.3–7.9 years). The MFD of saddles ranged from 19.4 to 42.3 μm, with CV(D) ranging from 18 to 35%. Regression analyses showed that samples taken from the midside site were good predictors of:

- saddle, neck and TF MFD;
- saddle, neck, and TF yield and cwt.

In addition:

- Sex, age and LWT were generally of little additional value in predicting the measured fibre attributes studied with the exception of some neck fibre diameter attributes. Male alpacas tended to have coarser TFs, mainly as a result of having relatively coarser pieces compared with the female alpacas. The neck was also coarser in the males in this study compared with the female alpacas. Older alpacas also tended to have coarser necks than younger alpacas. Therefore, the MS tended to underestimate the MFD of the TF of males and older animals compared with females and younger animals.
- Neither breed type nor property accounted for sufficient variation in fleece quality traits in this study and were not significant in any model.
- Generally, the alpacas with heavier LWTs (which were mostly the older animals and particularly the males) had coarser medullated fibres, than the animals of lower LWT. Therefore, the TF medullated fibre diameter characteristics were underestimated in the heavier, rather than lighter animals if LWT was not included in the model.

The significantly lower CWYs of the MS and neck compared with the CWYs of the saddle and pieces suggests that the distribution of dust, dirt and grease content is not equally distributed over the body. A full interpretation of the distribution of contaminants over the fleeces of alpaca should include the vegetable matter content, a measure that was not taken in the present work.

4.1. Predicting total fleece mean fibre diameter

In this study, the SGSMFD was a slightly better predictor for TFMFD than MSMFD. It was likely that the SGSMFD would be a better predictor for TFMFD because it contains fibres drawn from a larger surface area thus taking more of the 'between-location' variation into account. Both sample methods were highly correlated with TFMFD and ranking animals would be equally effective using either method. If the animals were being sampled at shearing, the SGS may be considered if labour was available, otherwise the MS would appear to be quite adequate.

4.2. Usefulness and prediction of coefficient of variation of mean fibre diameter

This experiment indicates that there is a large variation in CV(D) over the body. In each case, the fleece components (saddle, neck and TF) were only moderately correlated with the MSCV(D). Thus unlike Merino sheep, where the variation over the body is small enabling a single MS sample to be used to adequately predict the fleece CV(D) (Fleet et al., 1993), the MS is an inappropriate sampling site from which to estimate the saddle fleece component CV(D). Clearly the reason for this is that in alpacas, there is significant variation in the MFD over the body and this variation is associated with high variation in CV(D). The MS does not measure a large enough area of the fleece to detect sufficient variation in CV(D).

Variation in CV(D) is important in Merino wool, as it affects the processing performance of that wool (Martindale, 1945). CV(D) has been incorporated with MFD into the calculated term "spinning fineness", to enable breeders and processors to use one term that describes processing performance more reliably than MFD alone (Butler and Dolling, 1995). Spinning fineness is easily reconciled to MFD as it has been normalised using the benchmark of 24% CV(D), a value accepted as typical for Merino wool (Butler and Dolling, 1995).

The present work suggests that, for alpacas, spinning fineness should be normalised using a benchmark of 27% CV(D) (Table 1). However, if 27% CV(D) was adopted as the benchmark, it may cause confusion during testing and during specification for textile manufacturing operations as people are more familiar with the use and definition of spinning fineness for Merino wool.

The present work clearly indicates that breeders wishing to improve CV(D) and/or spinning fineness measurements of the alpaca saddle, in the most efficient way, should use the SGS, since MS will not be as accurate for use in the selection of stock for breeding programs.

NCV(D) was only moderately correlated with SGSCV(D) and MSCV(D). It is unlikely that the neck samples were contaminated with either S or P fleece as the neck fibre was quickly separated at shearing from the other fleece components. The neck fibre is visually quite different (shorter and more uniform staples) than the hairier longer apron or the saddle. Breeders using either the MS or SGS, to improve TF CV(D), will improve NCV(D) at the same time with similar effectiveness.

4.3. Ranking versus absolute values

The Merino sheep has developed a generally uniform fleece (Fleet et al., 1993) in response to long term selection by animal breeders. The selection process has resulted in a reduction in the variation of numerous characteristics throughout the fleece. In a similar experiment to this one, McGregor (1994) showed that cashmere fleece characteristics could not be accurately predicted using the MS, but could be predicted by a fleece grid sample. Couchman and McGregor (1983) have shown that a system of using three samples taken from along the mid-line of cashmere goats was a better predictor than the use of a single MS. Although not tested in this experiment, the three-site method is likely to be more representative than the MS site alone and avoids the need of shearing the entire alpaca in order to obtain a more representative sample of the saddle.

By using the ratios of the mean weights of the different fleece components (Table 1) it is possible to suggest a sampling regime which could involve the sampling of staples from the different components of the TF. Such a representative sampling would have one neck, three pieces and six saddle staples each of similar weight. This type of approach clearly needs the taking of staples in multiples of 10 to obtain the correct ratio of samples but it may be suitable for competitions and for stud sales.

4.4. Sampling variance and 95% confidence limits of fleece tests results

Sampling variance for MFD and S.D. were similar to those reported for Merino wool (Anon., 1973). CLs for MFD (± 1.6 μm) show that alpaca breeders and advisors need to exercise caution when interpreting absolute fibre test results rather than animal ranking on tests results and in applying them in selection programs. Small differences in MFD are unlikely to be valid grounds upon which to discriminate against animals. This interpretation has even greater weight when using SGS to select animals, as the sampling variance for SGS test results is at least twice that of MS test results.

Although this may seem to contradict earlier statements, in some breeding programs, it may be preferable to use the MS for the selection of alpacas for all fibre attributes. The determination of the best sampling site to use in a breeding program would depend on availability of skilled labour to take the SGS, the reduced variance in fibre test results from the MS and on the design and number of animals in a breeding program.

The greater variance in medullated test measurements is likely due to the following:

1. Greater variability in the distribution of medullated fibres over the saddle compared with the MS;
2. Random differences in the effectiveness of separation of the shorn fleece into its components;
3. The smaller number of samples in the medullated fibre test owing to the restriction on the test method to white fleeces;
4. The precision required during testing to ensure that samples presented are unbiased;
5. Potentially the presence of coloured fibres in the samples tested. It is also difficult to prevent cross fibre contamination during normal alpaca fleece shearing operations.

The relatively large variance for CWY suggests that the practice of some commercial test houses in making only one estimate for CWY is fraught with danger, especially if the results of such testing are to be used in genetic selection programs. CWY measurements can clearly have great variance indicating that careful investigators will insist on the testing of duplicate samples and the retesting of any results that are outliers.

4.5. Practical issues in using the midside sample and saddle grid sample

The MS is easy to locate and does not require shearing the entire fleece. However, when the MS does not represent the variation in the TF, an alternative sampling method is required. SGS would be expected to incorporate more of the variation than the MS because it contains fibres from a larger proportion of the fleece. However, the disadvantage of using the SGS is that the entire saddle fleece must be shorn, which in some situations is not desirable or possible. Such situations include, testing of fleeces prior to shearing to aid fleece classing and lot building, testing of sires and breeding stock prior to mating, selling of animals in mid winter and live animal fleece judging competitions.

The MS was a poor sampling site from which to predict all three medullated fibre characteristics. Clearly the variation in each medullation characteristic over the saddle and TF was greater than at the MS site. The structure of the alpaca fleece is such that there is a high percentage of coarse, medullated fibres on the extremities of the shorn fleece, namely in the pieces comprising the legs, belly and apron. It is therefore not surprising that the MS could not accurately predict the medullated fleece characteristics. However, the SGS was a better sample for the prediction of each medullation characteristic in the TF even though the variance in the SGS medullation measurements was much greater than those for MS.

5. Conclusion

If alpacas are to be selected for characteristics such as low MFD and high fleece weight the midside sampling site is recommended. However, if alpacas are to be selected for low MFD coefficient of variation, low incidence of medullated fibres and other characteristics of medullated fibre, then the saddle grid sampling is recommended as the optimal sampling technique. No significant effect of breed type or location on predictive models was detected and provided that alpacas were measured in similar age and sex classes no biases would occur in reliability of the use of midside or SGSs. The large 95% CLs for all the tested fibre attributes indicate that alpaca breeders and advisors need to consider taking suitable duplicate measurements and other precautions during breeding and animal selling programs.

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Appendix A. A list of abbreviations, their definition and values

Symbol	Definition
S	Saddle
N	Neck
P	Pieces (belly, apron, head, front legs, back legs, floor sweepings)
MS	Midside sample
TF	Total fleece = S + N + P + MS or the weighted mean of these values
SGS	Saddle grid sample
gwt	Greasy fleece weight (kg)
cwt	Clean fleece weight (gfwt × CWY, kg)
LWT	Live weight (kg)
CWY	Clean washing yield (%)
MFD	Mean fibre diameter (μm)
S.D.	Standard deviation of MFD (μm)
CV(D)	Coefficient of variation of MFD (%)
Med	Incidence of medullated fibres (%)
Medwt	Weight of medullated fibres (% (w/w))
MedMFD	MFD of medullated fibres (μm)
MedSD	S.D. of MedMFD (μm)
MedCV(D)	Coefficient of variation of MedMFD (%)

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