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Consequences of Differing Wool Growth Rates on Staple Strength of Merino Wethers with Divergent Staple Strengths

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Summary

An experiment was conducted to determine the effects of dietary protein intake after a period of weight loss on the wool components of staple strength for sheep with a history of low or high staple strength (18.0 vs 34 N/ktex). After being fed to lose 15% of their liveweight over 10 weeks, sheep within each staple strength group were assigned in equal numbers to either a low or high protein diet designed to re-gain initial liveweight in 8 weeks. Liveweight, feed intakes and the growth, fibre diameter and fibre length characteristics of wool were measured at regular intervals.

After the weight loss and growth regimes were imposed there was no difference in staple strength between the low and high staple strength groups (14.4 and 14.9 N/ktex, respectively). However, coefficient of variation (CV) of fibre diameter remained significantly different between staple strength groups. Wool growth rate at the time of diet change was the only significant component of wool growth and fibre measurements that was significantly correlated with staple strength.

Supplying a high protein diet after a period of weight loss increased wool growth. This changed the position of break along the staple and increased the fibre diameter at the point of break from 13.0 to 13.9 μm without affecting staple strength. It also increased fibre diameter and mean fibre length growth rate. The low staple strength group had a significantly higher CV of fibre length than the high staple strength group. Fibre length growth rate to fibre diameter ratio was stable over time in the high staple strength phenotype but declined with time in the low staple strength line.

The results suggest that large weight losses will reduce the difference in staple strength between animals with a history of large difference in staple strength. Rate of wool growth after the point of break did not influence this staple strength outcome.

Keywords: wool growth, staple strength, fibre diameter, fibre length, weight change, protein intake

Introduction

In Mediterranean environments, wool growth rate and fibre diameter fluctuate in response to pasture quality and availability (Bellotti et al. 1992). The seasonal nature of pasture growth in much of Australia's wool producing areas results in approximately 28% of the Australian Merino fleece wool being classified as tender (< 30 N/ktex) in the 1993/94 selling season (Thompson et al. 1995a). Staple strength is a major determinant of Hauteur (Anonymous 1988) and may also effect the properties of yarn and fabric (Plate et al. 1987; Lamb and Yang 1994). Genotype (Lewer and Ritchie 1993; Lewer and Li 1995), nutrition (Hansford and Kennedy 1990; Doyle et al. 1994; Schlink and Dollin 1995), physiological status (Masters et al. 1993) and environmental factors (Bray et al. 1995; Butler and Head 1992) all influence the components of the staple that contribute towards its strength. In young sheep Doyle et al. (1995) showed that liveweight gain with supplementation on dry pasture was a prerequisite to achieving sound wool from spring shorn sheep.

Sheep with high staple strength have a reduced coefficient of variation (CV) of fibre diameter (Lewer and Li 1995). Bray et al. (1995) reported a correlated response in standard deviation of fibre length of a 40 mm staple section in Romney sheep selected for staple strength (standard deviations of 7.92 and 5.07 mm in the low and high staple strength lines, respectively). The lower variability of fibre length was accompanied by greater regularity of crimp and lower CV of fibre diameter in the high staple strength line. In a physical model of staple strength de Jong et al. (1985) demonstrated that the peak force measurement used in staple strength determinations was sensitive to changes in fibre length distributions. Although they claimed the distribution of fibre length in Merino sheep staples was not sufficient to affect the peak force measurements of staple strength.

Studies into the effects of nutritional change on staple strength to date have concentrated on achieving different degrees of liveweight loss before re-feeding to reach similar body weights at termination of the experiments (Hansford and Kennedy 1990; Thompson et al. 1995a,b). The experiment reported in this paper uses similar patterns of liveweight loss and re-gain but manipulates wool growth by varying the amount of crude protein in the feed on offer. This was undertaken to determine the effects after weight loss of re-feeding diets designed to achieve similar liveweight gains but divergent wool growth in Merino wethers previously selected in the field on the basis of prior low and high staple strengths on wool growth, fibre diameter, fibre length and staple strength.

Studies into the effects of nutritional change on staple strength to date have concentrated on achieving different degrees of liveweight loss before re-feeding to reach similar body weights at termination of the experiments (Hansford and Kennedy 1990; Thompson et al. 1995a,b). The experiment reported in this paper uses similar patterns of liveweight loss and re-gain but manipulates wool growth by varying the amount of crude protein in the feed on offer. This was undertaken to determine the effects after weight loss of re-feeding diets designed to achieve similar liveweight

Materials and Methods

Selection of Sheep

Twenty four wethers (12 low and 12 high staple strength), initial liveweight 62.7±1.0 kg, were selected from flocks used to establish the genetic parameters of wool staple strength (Howe et al. 1991). For each staple strength group, the wethers were selected for their consistent staple strength over two consecutive shearings and representing the average staple strength for the groups. The wethers were also chosen so that both staple strength groups had the same average fibre diameter. The low and high staple strength groups averaged 18.4±1.8 and 34.0±3.8 N/ktex, respectively, based on two previous annual shearings at the Great Southern Agricultural Research Institute, Katanning, Western Australia. The sheep used in the experiment were born in July,1989 and transferred to the animal house at CSIRO, Perth, Western Australia in January, 1992.

Diets and Measurements

All sheep were fed (Table 1) to achieve approximately 15% loss in liveweight over a 10 week period. The two staple strength groups were then sub-divided and fed an iso-energetic ration of either low or high protein content (Table 1) for a further 8 weeks to re-gain the weight lost in the restricted phase.

At the completion of regaining initial liveweight, the sheep were released from the pens onto green pasture until shearing in September.

Sheep were weighed at weekly intervals, and between weeks 1 and 19 defined mid-side wool patches were clipped at 2 weekly intervals. The clipped areas were traced onto clear plastic sheets and the dimensions measured with image analysis (Video Trace, Leading Edge Pty., South Australia). Mid-side patch wool was washed in detergent (Teepol), water, ethanol and two changes of Shell X2 prior to drying, conditioning and weighing. Clean patch wool production was calculated as mg clean wool/100 cm^2.14 days. The standard deviation, CV and mean fibre diameter of the patch wool was measured with an Optical Fibre Diameter Analyser (OFDA) (BSC Electronics, Western Australia) on wool mini-cored (2 mm diameter) from the mid-side patch clippings.

Dye bands were applied approximately 50 mm anterior to the mid-side wool patch on days 7, 35, 77, 105, 133 of the experiment and dye banded wool was removed prior to shearing along with mid-side samples for raw wool measurements. The dye banded staples were cut along the base of each dye band, the segments weighted and the proportion of wool between dye bands determined for each sheep. Dye band segment weights were accumulated to estimate the position of break along the staple.

Table 1 Composition of feeds offered and proximal composition.

Ration Ingredients (% as fed basis)	Restricted	High Protein	Low Protein
Straw	48.5		
Field hay	47.8		
Lucerne hay		30.1	10.7
Oaten hay		37.1	61.1
Oaten grain			11.5
Starch		1.6	4.3
Lupins		18.8	10.3
Fish meal		8.0	
Urea	1.7	0.6	
$CaSO_4$		0.7	0.1
SIROMIN[A]	2.2	2.0	2.0
Ration Proximal Composition (%)			
Dry matter	90.1	89.6	88.3
Organic matter in dry matter	95.6	92.1	94.9
Dry matter digestibility	50.8	71.1	67.3
Crude protein	12.8	31.0	15.2

[A] Containing the following elements: (g/kg) Na 176, Ca 48, S 39, P 15, Mg 4, K 116; and (mg/kg) Fe 1940, Mn 580, Zn 1160, Cu 116, Mo 40, I 4, Co 80, Se 6, Ni 4, Cr 4, V 4, B 4.

Fibre length growth rate and diameter were determined throughout the experiment using the [^{35}S]-cysteine technique as described below. Each sheep received intra-dermally the equivalent of 3.5 mCi [^{35}S]-cysteine (calculated at the start of the experiment) into a marked mid-side site with repeated doses administered into the same site. Intra-dermal injections of [^{35}S]-cysteine in 0.25ml of normal saline were administered on days 0, 7, 14, 56, 63, 70, 77, 84, 91, 112, 119, and 126 of the experiment. Fibres were clipped from the site 14 days after the final injection, washed, stained with picric acid and mounted on microscope slides with gelatine (5% weight:volume). The fibres were then exposed to X-ray film (Fuji Medical X-Ray Film, Fuji, Japan) for approximately 14 days. Films were developed and superimposed onto the fibres with DPX. Fibre length growth in mm/day was measured by tracing fibre length between the labelled injection points and fibre diameter in mm on the fibre at the start of the [^{35}S] image with the image analysis system. For each sheep, 50 randomly selected fibres from the [^{35}S]-cysteine injection site were measured for fibre length growth rate and fibre diameter.

Sheep were shorn approximately 3 months after the completion of the pen experiment. The dye bands were removed immediately prior to shearing, and at shearing greasy fleece weight was recorded and a mid-side sample removed for further analysis. Mid-side fleece samples were measured for yield, fibre diameter and its variation, staple length and strength, and point of break. Yield was determined according to the Australian Standards (AS 1134). Mean fibre diameter, standard deviation and CV

were determined on a scoured, mini-cored, mid-side sample with an OFDA. Staple strength and length were determined on the dye banded staples, with staple strengthbeing determined between the initial and final dye-bands on the staple using an Agritest 'Staple Breaker' system (Agritest Pty Ltd, Sydney) according to the manufacturer's operating instructions. The tip and base of each staple broken in the strength test were weighed and the weight of the tip as a proportion of the total staple weight was used to calculate the percentage point of break.

At the point of staple break, fibre shedding rates were determined using the technique of Schlink and Dollin (1995). Fibre diameter was measured at the point of break for broken fibres and immediately above the sheath or brush end for shed fibres using a projection microscope (Reichert, Australia).

Approximately 250 fibres from two staples of each sheep were measured to determine fibre diameter at the point of break and shedding rates.

Feed Analysis

Dry and organic matter content of the feeds were determined by the methods of Faichney and White (1983). Feed dry matter digestibility was determined by in vitro analysis (Klein and Baker, 1993) and crude protein using standard procedures for the Tecator 1030 Kjeltec Auto Analyser.

Statistical Analysis

The data were analysed using the computer program Minitab (Minitab Inc., USA). The effects of staple strength group, nutritional treatment and time were assessed using a general linear model (GLM). In the cases where there were no staple strength group x nutritional x time interactions, the results were pooled across time to give a mean for the entire experimental period. GLM was also used to produce individual periods means for staple strength group and diet. The simple linear relationships between individual sheep parameters reported were determined using linear regression.

Results

Liveweight Change and Feed Intake

Liveweights declined by 15.2% during the 10 weeks of restricted feeding (62.6 to 53.1 kg), and then increased over the next 8 weeks to their starting liveweights. At no time did liveweights differ significantly between the staple strength groups, and liveweight gain during re-feeding was not influenced by the diet offered to the sheep.

Dry matter and crude protein intakes averaged 435 and 59 g/day, respectively, during the 70 days of restricted feeding, and did not differ between staple strength groups. On re-feeding, the average intake of dry matter was 1025 g/day for both staple strength groups, and the average protein intake was 189 and 309 g crude protein/day for the low and high protein diets respectively (P<0.05).Ther were no significant differences in dry matter intake between protien treatments or crude protien intake between staple strength groups.

Fleece Characteristics

Clean fleece weight, mean fibre diameter, staple length and staple strength did not differ significantly between staple strength groups or nutritional treatments (Table 2). The average CV of fibre diameter was significantly (P<0.001) lower for sheep from the high than the low staple strength group. There was a significant interaction between staple strength group and diet (P<0.05) for fleece CV of fibre diameter where the high staple strength group fed a high protein diet had a significantly lower CV of fibre diameter than the other 3 treatment groups. Position of break was estimated to be at approximately the time of diet change for all groups of sheep despite significantly altering the staple point of break.

Table 2 Fleece and mid side wool measurements (±SEM) from low and high staple strength groups losing weight for 10 weeks and then fed to re-gain starting liveweight with a low (LP) or high protein (HP) diet for 8 weeks (FD, fibre diameter; n.s., not significant).

Staple Strength	Low		High		Significance Level	
	LP	HP	LP	HP	Group	Diet
Clean fleece weight (kg)	4.2±0.1	4.2±0.2	3.8±0.2	4.1±0.1	n.s.	n.s.
Mean Fibre Diameter (µm)	20.8±0.5	21.1±0.7	21.0±0.5	22.0±0.4	n.s.	n.s.
FD standard deviation (µm)	5.5±0.2	5.3±0.1	5.4±0.2	5.0±0.2	n.s.	n.s.
FD coefficient variation (%)	26.4±0.7	26.1±0.5	25.5±0.3	22.5±0.6	0.001	0.01
Staple strength (N/ktex)	15.3±2.1	13.4±1.3	15.0±0.9	14.7±1.3	n.s.	n.s.
Staple length (mm)	102±3	101±2	104±3	101±3	n.s.	n.s.
Staple point of break (% from tip)	69±1	65±1	70±2	66±1	n.s.	0.01
Week 11 dye-band (% from tip)	69.1±1.0	67.1±1.4	71.0±3.5	66.1±1.7	n.s.	n.s.

Fibre diameter at the point of break was not significantly different between the staple strength groups (Table 3) but was affected by diet quality on re-feeding with 13.0 and 13.9 µm for the low and high protein diets, respectively. Fibre diameter standard deviation at the point of break was significantly different between the staple strength groups but was not affected by the nutritional treatments. The incidence of shed fibres ranged from 8% for the high protein, high staple strength group to 16.1% for the low protein, low staple strength sheep but these differences were not significant.

Table 3 Wool fibre parameters (±SEM) at the point of break from low and high staple strength groups losing weight for 10 weeks and then fed to re-gain starting liveweight with a low (LP) or high protein (HP) diet for 8 weeks (FD, fibre diameter; n.s., not significant; no significant interaction between group and diet).

Staple Strength	Low		High	Significance Level		
	LP	HP	LP	HP	Group	Diet
FD (μm)	13.3±0.4	14.3±0.4	12.8±0.4	13.5±0.3	n.s.	0.05
FD standard deviation (μm)	3.1±0.2	3.7±0.2	2.8±0.2	2.7±0.4	0.05	n.s.
FD coefficient variation (%)	23.2±1.9	26.0±1.8	21.8±1.4	20.0±2.3	n.s.	n.s.
Shed fibres (%)	16.1±5.8	10.7±2.1	13.9±3.9	8.0±2.8	n.s.	n.s.
FD shed fibre (μm)	13.9±1.4	14.9±1.8	13.3±1.2	13.3±0.7	n.s.	n.s.
Shed fibre FD standard deviation (μm)	4.9±0.8	6.3±1.2	3.8±1.0	3.7±0.5	n.s.	n.s.
Shed fibre FD coefficient variation (%)	34.8±4.6	41.6±6.9	29.3±7.2	27.7±2.5	n.s.	n.s.

Wool growth and fibre diameter

Clean wool growth (Table 4) and fibre diameter (Table 5) of the mid side patch wools were not significantly different between the staple strength groups, but protein intake influenced wool growth and fibre diameter during re-feeding. Patch clean wool growth rates averaged 986 and 1279 mg/100 cm^2.14 days with average mean fibre diameters of 21.2 and 22.5 μm for the low and high protein diets, respectively, in the last measurement period of the experiment.

Table 4 Mid-side patch clean wool production for 14 day intervals (mg/100 μm±sem) from low and high staple strength groups losing weight for 10 weeks and then fed to re-gain starting liveweight with a low (LP) or high protein (HP) diet for 8 weeks (n.s., not significant; no significant interactions between group and diet).

Staple Strength	Low		High		Significance Level	
Week of clipping	LP	HP	LP	HP	Group	Diet
Week 3	992±42	915±42	932±66	973±59	n.s.	n.s.
Week 5	717±51	632±32	643±44	628±48	n.s.	n.s.
Week 7	433±36	385±14	416±24	394±32	n.s.	n.s.
Week 9	317±43	282±18	272±21	269±31	n.s.	n.s.
Week 11	249±43	245±19	196±13	254±26	n.s.	n.s.
Week 13	369±67	402±37	364±54	426±53	n.s.	n.s.
Week 15	801±66	970±39	804±86	1059±120	n.s.	0.05
Week 17	858±79	1058±44	813±166	1080±98	n.s.	0.05
Week 19	1042±74	1271±52	929±133	1288±121	n.s.	0.01

Table 5 Average mid-side patch fibre diameters for 14 day intervals (mm±sem) from low and high staple strength groups losing weight for 10 weeks and then fed to re-gain starting liveweight with a low (LP) or high protein (HP) diet for 8 weeks (n.s., not significant; no significant interactions between group and diet).

Staple Strength	Low		High		Significance Level	
Week of clipping	LP	HP	LP	HP	Group	Diet
Week 3	19.3±0.5	18.9±0.7	19.7±0.5	20.2±0.3	n.s.	n.s.
Week 5	17.5±0.4	17.4±0.7	17.5±0.4	18.1±0.3	n.s.	n.s.
Week 7	15.7±0.5	16.0±0.6	16.1±0.5	16.5±0.3	n.s.	n.s.
Week 9	15.3±0.5	15.5±0.5	15.2±0.5	15.3±0.2	n.s.	n.s.
Week 11	15.1±0.5	15.2±0.4	14.6±0.3	14.5±0.3	n.s.	n.s.
Week 13	17.0±0.8	17.7±0.6	17.3±0.6	17.8±0.5	n.s.	n.s.
Week 15	19.2±0.7	20.8±0.7	19.8±0.4	21.6±0.8	n.s.	0.05
Week 17	20.2±0.5	21.6±0.6	20.9±0.5	22.7±0.8	n.s.	0.05
Week 19	21.0±0.4	21.9±0.4	21.4±0.7	23.1±0.7	n.s.	0.05

Fibre diameter and length growth

Fibre diameters of [^{35}S]-labelled fibres were significantly lower on days 56 and 63 of the weight loss period for the high staple strength sheep. Fibre diameters averaged 18.5 and 16.9 µm for the low and high staple strength groups, respectively (Table 6). Mean fibre diameter was not significantly different between the staple strength groups during the other observation periods. The change in diameter of [^{35}S]-labelled fibres followed a similar pattern on re-feeding as those seen for the mid-side wool patch samples. However, the average fibre diameter of mid-side patch wool was significantly less than that of the overall average for [^{35}S]-labelled fibres (18.3 vs 22.8 µm; $P<0.01$)

Fibre length growth rates differed significantly between groups at the start of the experiment (days 0 to 7) averaging 393 and 368 µm/day for the low and high staple strength groups, respectively (Table 7). There were no further significant differences in average fibre length growth rate between staple strength groups at subsequent measurement periods for the duration of the experiment. Within individual time periods, the dietary regimes had no significant effects on fibre length growth rate. Average fibre length growth rates for low and high staple strength sheep were not significantly different, averaging 365 and 378 µm/day respectively.

Low staple strength sheep had significantly more variation in fibre length growth rate at the initiation of the experiment and immediately after the commencement of liveweight re-alignment (Table 8). The average CVs of fibre length growth were 11.6 and 10.5% for the low and high staple strength sheep, respectively ($P<0.05$). There was no significant relationship between CV of fibre diameter and CV of fibre length for individual experimental periods but there was a low but significant relationship for the combined data set ($r^2=0.09$; $P<0.001$).

Table 6 Fibre diameter (μm±sem) on specified days for [^{35}S]-cysteine labelled wool fibres from low and high staple strength groups losing weight for 10 weeks and then fed to re-gain starting liveweight with a low (LP) or high protein (HP) diet for 8 weeks (n.s., not significant; no significant interactions between group and diet).

Staple Strength	Low		High		Significance Level	
Day of Experiment	LP	HP	LP	HP	Group	Diet
0	23.5±0.9	22.8±1.3	23.2±1.0	22.8±0.6	n.s.	n.s.
7	22.9±0.9	22.5±1.0	22.6±0.9	22.8±0.7	n.s.	n.s.
14	22.3±0.9	22.2±1.1	21.6±0.8	22.2±0.7	n.s.	n.s.
56	18.3±0.8	18.9±0.7	16.8±0.5	16.9±0.5	0.05	n.s.
63	17.8±0.8	18.8±0.7	16.5±0.4	17.2±0.6	0.05	n.s.
70	17.6±1.1	18.5±0.7	16.7±0.5	17.3±0.7	n.s.	n.s.
77	21.4±1.3	24.0±1.3	21.2±0.8	22.7±0.8	n.s.	n.s.
84	23.6±1.3	26.1±1.2	23.3±0.8	26.1±0.9	n.s.	0.05
91	24.9±1.2	27.0±1.1	24.5±0.9	26.6±1.0	n.s.	n.s.
112	25.8±1.0	29.2±1.1	25.6±1.0	27.7±1.2	n.s.	0.05
119	26.8±1.0	29.4±0.9	26.6±1.7	27.7±1.3	n.s.	n.s.
126	26.2±0.9	29.5±1.1	26.2±1.2	28.0±1.1	n.s.	0.05

Table 7 Fibre length growth rate (μm/day±sem) for the specified periods on [^{35}S]-cysteine labelled wool fibres from low and high staple strength groups losing weight for 10 weeks and then fed to re-gain starting liveweight with a low (LP) or high protein (HP) diet for 8 weeks (n.s., not significant; no significant interactions between group and diet)

Staple Strength	Low		High		Significance Level	
Days of Experiment	LP	HP	LP	HP	Group	Diet
0- 7	395±11	390±12	374±5	361±13	0.05	n.s.
8-14	391±13	392±10	377±8	359±15	n.s.	n.s.
15-56	341±13	338±9	331±8	307±11	n.s.	n.s.
57-63	294±13	313±8	284±11	265±11	n.s.	n.s.
64-70	294±18	311±6	293±10	277±16	n.s.	n.s.
71-77	331±22	340±10	320±15	305±14	n.s.	n.s.
78-84	378±16	407±13	390±18	393±18	n.s.	n.s.
85-91	405±12	434±7	405±17	427±19	n.s.	n.s.
92-112	408±16	436±8	413±21	418±20	n.s.	n.s.
113-119	427±11	452±5	421±18	434±16	n.s.	n.s.
120-126	429±14	448±10	436±15	429±17	n.s.	n.s.

Fibre length/fibre diameter growth rate (L/D) ratio was not significantly different between staple strength groups or measurement periods. L/D ratio was not significantly ($P>0.05$) affected by protein intake, ratio being on average 16.6 and 15.8 for the low and high protein intakes, respectively. The L/D ratio of the low staple strength sheep declined significantly with time ($P<0.05$) whereas the high staple strength sheep remained constant for the duration of the experiment .

Table 8. Fibre length coefficient of variation of (%±sem) for the specified periods on [^{35}S]-cysteine labelled wool fibres from low and high staple strength groups losing weight for 10 weeks and then re-feed with a low (LP) or high (HP) protein diet for 8 weeks (n.s., not significant; no significant interactions between group and diet).

Staple Strength	Low		High		Significance Level	
Days of Experiment	LP	HP	LP	HP	Group	Diet
0- 7	10.7±1.0	11.7±0.9	10.0±1.2	8.4±0.6	0.05	n.s.
8-14	12.4±1.5	11.6±0.7	11.99±0.7	10.0±1.0	n.s.	n.s.
15-56	11.1±0.5	10.2±0.7	9.9±1.1	9.6±0.7	n.s.	n.s.
57-63	13.5±0.9	14.4±1.5	12.5±1.5	12.6±0.6	n.s.	n.s.
64-70	14.4±0.9	13.3±0.9	14.6±2.7	11.9±1.7	n.s.	n.s.
71-77	14.2±0.8	12.9±1.0	10.9±0.8	12.6±0.9	0.05	n.s.
78-84	11.9±0.4	9.9±0.8	10.0±0.8	10.1±0.4	n.s.	n.s.
85-91	14.1±1.2	9.9±0.6	10.0±0.5	10.1±0.7	0.05	0.05
92-112	9.8±0.8	8.8±0.6	7.9±0.4	8.4±0.6	n.s.	n.s.
113-119	9.4±0.5	9.6±0.5	10.4±0.8	9.5±1.2	n.s.	n.s.
120-126	11.6±0.9	8.8±0.6	9.1±0.8	8.9±0.9	n.s.	n.s.

Correlates of Staple Strength

There was a significant correlation between staple strength and clean wool growth rate at the time of minimum wool growth (week 11) (r^2=0.35, P=0.002). Fibre diameter at the point of break (patch and broken fibres), rate of change of fibre diameter from minimum fibre diameter to the end of the experiment, percentage of shed fibres, average fibre length growth rate, and sheep average variation in fibre diameter and fibre length growth were not significantly correlated with staple strength.

Discussion

The differences in staple strength between the staple strength groups observed under field conditions were not apparent after the sheep lost 15.2% of their liveweight in 10 weeks, followed by recovery of this weight during the following 8 weeks. The only wool variable found in this experiment to be significantly related to staple strength was clean wool production at the time of diet change. This is contrary to the findings of Hansford and Kennedy (1990), Dollin et al. (1995) and Thompson et al. (1995a,b) who found a number of wool variables were correlated with staple strength. The lack of correlation between staple strength and fibre diameter at point of break, rate of change in fibre diameter, fibre diameter variation and fibre shedding may reflect the narrow range of staple strengths achieved in this experiment (range of 11.8 N/ktex) compared to the wider range of staple strengths in the previous reports.

Nutritional differences during the subsequent liveweight re-alignment produced significant differences in the position of break along the staple. This shift in position of break is probably accounted for by increased wool mass from increased wool growth in sheep on the high protein diet. High protein intake also resulted in higher fibre diameter at the point of break than the sheep fed the low protein diet. Mata et al. (1990) and Revell (1992) proposed that when the body reserves of protein are depleted, an increase in intake by the sheep will result in the repletion of body reserves before responses in wool growth. The high protein diet in this study was formulated to provide surplus amino acids for wool growth in excess of body requirements as calculated by Neutze (1990), unlike the low protein diet where less amino acids were available for wool growth. The response obtained in fibre diameter at the point of break supports the suggestion that surplus absorbed protein was available for wool growth. This may have allowed for an earlier increase of fibre diameter after the extended period of weight loss in which body reserves of protein were depleted. Hence, if there is a lower quantity of protein available from the diet after a period of weight loss, wool growth increase is not immediately initiated and priority is given to tissue production until its demand for absorbed protein are met, after which time wool growth resumes. This difference in wool fibre diameter immediatly after weight loss with high protien intake is most likely to be a short term effect on fibre diameter as there was not a significant effect on the estimated time of the point of break.

Low and high staple strength groups had significantly different mid-side CV of fibre diameter at the post experimental shearing as predicted by Lewer and Li (1994), who found a high genetic association between the two traits. Selection across flocks for staple strength on the basis of CV of fibre diameter is likely to be misleading. Our data showed a significant interaction between staple strength group and diet for CV of fibre diameter. This suggests a strong non-genetic environmental component to fibre diameter variation, where sheep have been subjected to changes in nutritional regimes with time. This environmental effect in fibre diameter variation also occurred on a short-term basis as seen in CV of fibre diameter of broken continuous fibre at the point of staple break. CV of fibre diameter was not significantly different for the wool patch samples at the point of break. However, CV of fibre diameter for ends of fibres broken during staple strength testing were significantly different between the staple strength groups. There appears to be a considerable amount of flexibility in fibre diameter variation in both short and longer term basis suggesting that CV of fibre diameter is sensitive to nutritional changes. This supports the observations of Lang (1945) that as wool production decreased, the coarser fibres suffered little change in fibre diameter whereas the finer fibres underwent considerable change in fibre diameter.

Although there is a strong relationship between staple strength and CV of fibre diameter for sheep grazing in seasonal environments (Lewer and Li 1994), there is a weak relationship between variation in fibre diameter and that of fibre length growth rate. This weak relationship suggests that fibre length and fibre diameter are more independent than has been previously reported (Reis 1992). The efficiency of using CV of fibre diameter to select for staple strength may be significantly reduced where there is low along fibre variation in fibre diameter but no account has been taken of fibre length variation within the staples.

Bray et al. (1995) found that Romney sheep selected for high staple strength had lower variability in fibre length in 40 mm portions of staples than sheep selected for low staple strength. We found similar differences in fibre length variation in Merinos selected on the basis of past staple strength. The variation in fibre length observed confirm the predictions of de Jong et al. (1985) that a reduction in fibre length variation would lead to increased peak force required to break staples. They also went on to state that "variation in the distribution of fibre length in Merino wool staples is not sufficient to affect peak force". Although variation in fibre length was detected between the staple strength phenotypes there was no relationship between staple strength and fibre length variation in our experiment. This would suggest that other components of staple strength which were not included in the de Jong model probably play a more significant role in the determination of staple strength where staple strength is low.

The incidence of shed fibres and their fibre diameter reported here for housed sheep were similar to those for grazing wethers (Schlink and Dollin 1995). There was no significant difference in fibre shedding rates between these staple strength groups. This contrast with Adams et al. (1997) using a similar liveweight change in sheep genetically selected for staple strength differences reporting a significant difference in fibre shedding rates between the lines. Fibre diameter at the point of break of continuous fibres is similar to shed fibres and is similar to the results of Dollin et al. (1995). However, the variation in fibre diameter of the shed fibres is almost double those observed for continuous fibres at the point of break. This should be treated with caution due to the non-segregation of brush-ends and club-ends, as well as the low number of shed fibres involved in the estimations of shed fibre diameter.

The lack of responsiveness in staple strength to protein intake was similar to that reported previously for Romney sheep selected for low or high staple strength (Bray et al. 1995). The fibre diameter and wool growth responses to the high protein diet were within the ranges expected for the addition of high quality proteins to the diet (Neutze 1990; Murray et al. 1990). Fish meal is considered to be a good source of rumen escape protein to increase wool production (Hussein and Jordan, 1991) due to the high sulphur amino acid content.

For most time intervals measured the L/D ratio did not differ significantly between the staple strength groups, the changes during the experiment in L/D ratio over time were greater for the low than the high staple strength group. Schlink et al. (1996) also reported increased seasonal variation in L/D ratio of low staple strength sheep compared to that of high staple strength sheep. The change in L/D ratio for the low staple strength sheep was similar in magnitude to that reported by Hynd (1989) but contrary to the findings of Reis (1992) where L/D ratio was constant across nutritional regimes. The findings of Reis (1992) for sheep in pens are in contrast to the wide seasonal variations reported for grazing Romney (Woods and Orwin 1988) and Merino sheep (Schlink et al. 1996).

We observed significant differences in fibre diameters between mid-side patch wools and [^{35}S]-labelled fibres. These difference were consistent with the differences between the minimum fibre diameter for the [^{35}S]-labelled fibres and the fibre diameter of continuous fibres at the point of break on staple testing. Problems of wool sample selection bias are well recognised in industry standards for fibre diameter determination with considerable attention being given to wool sampling procedures (Baxter 1994). This suggests that previous reports (e.g. Hynd 1989; Hynd 1994) which make use of [^{35}S]-labelled fibres for fibre length and patch measurements for fibre diameter estimation are probably under-estimating the fibre diameter of the labelled fibres for fibre length determination to calculate the L/D ratio.

Our results show that the difference in staple strength between staple strength phenotypes was reduced by a 15% weight loss over 10 weeks. The rate of re-growth of wool did not significantly influence staple strength, although the diets used to influence wool growth did significantly alter the position of break and fibre diameter of continuous fibres at the point of break. The shift in fibre diameter at the point of break supports the hypothesis that if body reserves are depleted, then with restricted protein availability, muscle and viscera will be replenished before wool growth is increased above that of the base level by additional dietary inputs. The interaction between staple strength groups and diet in fibre diameter variation suggest that further study is required, including additional consideration of the relationship between fibre diameter and fibre length CV in respect to the effect on staple strength. There is a the poor relationship between fibre diameter and fibre length coefficients of variation indicating that in situations where there is little along fibre diameter variation, fibre diameter variation may be an inefficient means of selecting for staple strength.

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References

Adams, N. R., Briegel, J. R. and Ritchie, A. J. M. (1997). Wool and liveweight responses to nutrition by Merino sheep genetically selected for high and low staple strength. *Australian Journal of Agricultural Research* **48**, 1129-37.

Anonymous (1988). Report on trials evaluating additional measurements 1981-1988. [Australian Wool Corporation: Melbourne].

Baxter, B. P. (1994). Influences on comparisons between the mean fibre diameter of wools measured by airflow and by projection image methods. *Wool Technology and Sheep Breeding* **42**, 176-92.

Bellotti, W., Collins, W. and Moore, A. (1992). The Mediterranean environment. In "Management for Wool Quality in Mediterranean Environments", Eds. P. T. Doyle, J. A. Fortune and N. R. Adams, pp. 50-9 [Western Australian Department of Agriculture: Perth, Western Australia].

Bray, A. R., Merrick, N. C., Smith, M. C. and Scobie, D. R. S. (1995). Wool growth responses in Drysdale and high and low staple tenacity Romney sheep to nutrition supplementation in autumn. *Proceedings of the New Zealand Society of Animal Production* **55**, 54-7.

Bray, A. R., Scobie, D. R. and Woods, J. L. (1995). Genetic improvement in the wool strength of Romney sheep. *Proceedings of the 9th International Wool Textile Research Conference* **2**, 173-81.

Butler, L. G. and Head, G. M. (1992). Seasonal wool growth and the staple strength of wool from 9 Tasmanian flocks. *Proceedings of the Australian Society of Animal Production* **19**, 128-30.

de Jong, S., Kavanagh, W. J. and Andrews, M. W. (1985). Factors contributing to the staple strength of wool. *Proceedings of the 7th International Wool Textile Research Conference* **2**, 147-53.

Dollin, A. E., Schlink, A. C. and Jones, L. N. (1995). Merino wool fibre structural morphologies and wool strength. *Proceedings of the 9th International Wool Textile Research Conference* **2**, 143-51.

Doyle, P. T., Peter, D. W. and Masters, D. G. (1994). Prevention of low staple strength by nutritional means. In Adams, N. R. "Improving wool strength". *Proceedings of the Australian Society of Animal Production* **20**, 52-3.

Doyle, P. T., Plaisted, T. W. and Love, R. A. (1995). Supplementary feeding pattern and rate of liveweight gain in winter-spring affect wool production of young Merino sheep on the south coast of Western Australia. *Australian Journal of Experimental Agriculture* **35**: 1093-100.

Faichney, G. J. and White, G. A. (1983). Methods for the analysis of feeds eaten by ruminants [CSIRO: Melbourne].

Hansford, K. A. and Kennedy, J. P. (1990). The relationship between variation in fibre diameter along staples and staple strength. *Proceedings of the 8th International Wool Textile Research Conference* **1**, 590-8.

Howe, R. R., MacLeod, I. M. and Lewer, R. P. (1991). Genetic parameters for some wool tenderness related traits under different nutrition levels in Merino sheep. *Proceedings of the Australian Association of Animal Breeding and Genetics* **9**, 347-51.

Hussein, H. S. and Jordan, R. M. (1991). Fish meal as a protein supplement in ruminant diets: A review. *Journal of Animal Science* **69**, 2147-56.

Hynd, P. I. (1989). Effects of nutrition on wool follicle cell kinetics in sheep differing in efficiency of wool production. *Australian Journal of Agricultural Research* **40**, 409-17.

Hynd, P. I. (1994). Follicular determinants of the length and diameter of wool fibres. I. Comparison of sheep differing in fibre length/diameter ratio at two levels of nutrition. *Australian Journal of Agricultural Research* **45**, 1137-47.

Klein, L. and Baker, S. K. (1993). Comparison of the fractions of dry, mature subterranean clover digested in vivo and in vitro. *Proceedings of the XVII International Grassland Congress*, 593-5.

Lamb, P. R. and Yang, S. (1994). The effect of wool properties on spinning performance and yarn properties. In "Wool Spec 94 - Specification of Australian Wool and its Implications for Marketing and Processing", Eds. R. A. Rottenbury, K. A. Hansford and J. P. Scanlan, pp. R1-10 [CSIRO Division of Wool Technology: Sydney].

Lang, W. R. (1945). Growth changes in "tender" wool. *Journal of the Textile Institute* **36**, T2443-52.

Lewer, R. P. and Li, Y. (1994). Some aspects of selection for staple strength. *Wool Technology and Sheep Breeding* **42**, 103-11.

Lewer, R. P. and Ritchie, A. J. M (1993). Genetics of staple strength. In "Management for Wool Quality in Mediterranean Environments", Eds. P. T. Doyle, J. A. Fortune and N. R. Adams, pp. 104-14 [Western Australian Department of Agriculture: Perth, Western Australia].

Masters, D. G., Ralph, I. G. and Kelly, R. W. (1993). Wool growth from reproducing ewes. In "Management for Wool Quality in Mediterranean Environments", Eds. P. T. Doyle, J. A. Fortune and N. R. Adams, pp. 142-8 [Western Australian Department of Agriculture: Perth, Western Australia].

Mata, G., Peter, D. W. and Purser, D. B. (1990). Dietary changes, staple strength and point of break. *Proceedings of the Nutrition Society of Australia* **15**, 132.

Murray, P. J., Rowe, J. B. and Aitchison, E. M. (1990). The influence of protein quality on the effect of flavomycin on wool quality, liveweight change and rumen fermentation in sheep. *Australian Journal of Agricultural Research* **41**, 987-93.

Neutze, S. A. (1990). Use of wool growth response to estimate escape of protein supplements from the rumen. *Australian Journal of Agricultural Research* **41**, 761-7.

Plate, D. E. A. Robinson, G. A. and Rottenbury, R. A. (1987). The effect of staple strength and position of weakness of greasy wool on worsted spinning. *Journal of the Textile Institute* **78**, 269-80.

Reis, P. J. (1992). Length growth and diameter relationships of Merino wool fibres. *Wool Technology and Sheep Breeding* **41**, 52-5.

Revell, D. K., Baker, S. K. and Purser, D. B. (1994). Estimates of the intake and digestion of nitrogen by sheep grazing a mediterranean pasture as it matures and senesces. *Proceedings of the Australian Society of Animal Production* **20**, 217-20.

Schlink, A. C. and Dollin, A. E. (1995). Abnormal shedding contributes to reduced staple strength of tender wool in Western Australia. *Wool Technology and Sheep Breeding* **43**, 268-84.

Schlink, A. C., Mata, G., Lea, J. and Ritchie, A. J. M. (1996). Seasonal variation in fibre diameter and length growth rate in high and low staple strength Merino sheep. *Proceedings of the Australian Society of Animal Production* **21**, 356.

Thompson, A. N., Hynd, P. I., Peterson, A. D. and Ritchie, A. J. M. (1995a). Fibre strength and the proportion of discontinuous fibres in relation to staple strength in Merino sheep. *Proceedings of the 9th International Wool Textile Research Conference* **2**, 143-51.

Thompson, A. N., Peterson, A. D. Hynd, P. I. and Ritchie, A. J. M. (1995b). The failure properties of single fibres in relation to staple strength in Merino sheep. *Proceedings of the 9th International Wool Textile Research Conference* **2**, 134-42.

Woods, J. L. and Orwin, D. F. G. (1988). Seasonal variations in the dimensions of individual Romney wool fibres determined by a rapid autoradiographic technique. *New Zealand Journal of Agricultural Research* **31**, 311-23.