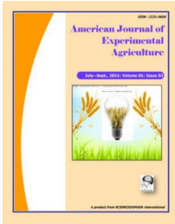

American Journal of Experimental Agriculture
2(1): 31-46, 2012

SCIENCEDOMAIN *international*
www.sciencedomain.org

Sire Genetics, Protein Supplementation and Gender Effects on Wool Comfort Factor in Australian Crossbred Sheep

A. E. O. Malau-Aduli[1*] and J. D. D. Akuoch[1]

[1]Animal Production and Genetics, School of Agricultural Science/Tasmanian Institute of Agricultural Research, University of Tasmania, Private Bag 54 Hobart, TAS 7001, Australia.

Research Article

Received 17th October 2011
Accepted 21st November 2011
Online Ready 19th December 2011

ABSTRACT

Aims: To investigate the effects of sire genetics, nutrition, level of supplementation, gender and their interactions on wool comfort factor (CF) and its correlation with other wool quality traits in crossbred sheep either grazing or supplemented with dietary protein.
Study design: A 5 x 2 x 2 x 2 factorial experimental design comprising five sire breeds, two dietary protein sources, two supplementation levels and two sexes respectively, was utilized.
Place and Duration of Study: University of Tasmania Farm, Cambridge, Hobart, Tasmania, Australia, between April 2008 and November 2010.
Methodology: Texel, Coopworth, White Suffolk, East-Friesian and Dorset sires were joined with 500 Merino ewes at a mating ratio of 1:100 in individual paddocks. Five hundred of the crossbred progeny were raised on pastures until weaning at 12 weeks of age. Forty of the weaners with an initial body weight (BW) range of 23-31 kg (average of 27 ± 3.2 kg) were fed with lupins or canola at 1 or 2% BW for 6 weeks in individual metabolic crates. CF and other wool quality traits were commercially measured at the Australian Wool Testing Authority, Melbourne. The data were analyzed in SAS using MIXED model procedures with sire fitted as a random effect, while sire breed, nutrition, supplement, level of supplementation and gender and their interactions were fitted as fixed effects.
Results: CF was significantly correlated with fiber diameter (-0.89), spinning fineness (-0.95) and wool curvature (0.33). Grass-fed sheep produced wool with significantly higher comfort factor (93.1±0.3%) than supplemented sheep (CF=85.9±1.1%). Sire genetics was a significant source of CF variation; White Suffolk crosses had the highest CF (90.1±8.7) and East-Friesian crosses the least (81.5 ± 10.1%). Males fed canola at 1%BW had the highest CF (90.8 ± 7.0%), while females fed lupins at 1% BW had the least (81.1±10.8%).
Conclusion: From a practical point of view, sheep farmers engaging in prime lamb production with wool comfort factor as an additional breeding objective should concentrate

---

**Corresponding author: Email: Aduli.MalauAduli@utas.edu.au;*

their effort on grass-feeding White Suffolk x Merino wethers. During the winter feed gap, supplementing the wethers with canola at 1% BW will not compromise wool CF.

Keywords: Sire genetics; crossbreds; wool; comfort factor; lupins; canola; grass-fed; sheep.

1. INTRODUCTION

When some wool fabrics are worn, a “prickle” sensation can be felt in the skin due to mechanical irritation from the coarser fiber ends on the skin surface. “Prickle” arises when a fabric has around 5% or more fibers exceeding 30 microns. Therefore, wool comfort factor (CF) is a key indicator of wool quality and is defined as the percentage of wool fibers with diameter less than 30 microns. Wool has been an important export commodity for the sheep industry in Australia. Recently, the profitability of wool exports has declined (Rowe, 2010; AWI, 2009). This was initially due to the collapse of the Australian wool reserve price scheme of 1991 (Bardsley, 1994). This reduced profitability has been exacerbated by drought in rural Australia, the escalating rise of the Australian dollar (Rowe, 2010), the rising cost of fertilizers, increasing competition with synthetic fibers and other major wool producing countries such as New Zealand, and the global economic down turn trends.

Australia still dominates world trade in the finer wool types used for apparel. This is because the Australian sheep flock is Merino-dominated. In Merino flocks, the major production traits include fleece weight, fiber diameter, live weight and reproduction (Fogarty et al., 2006). Other traits including those associated with product quality (wool staple strength; comfort factor, spinning fineness, carcass yield, muscle depth) and disease, may also contribute to profitability (Fogarty et al., 2006; Safari and Fogarty, 2003; Atkins, 1980). The Merino-dominated flock structure is expected to continue into the foreseeable future despite the increasing interest of sheep breeders in making profits from both wool and meat. However, as wool price declines and meat price rises, the wool industry is experiencing a swift change to the more profitable sheep meat industry. In Australia, the lamb industry is almost entirely based on crossbreeding which uses Merino, crossbreds and dual-purpose ewes that are joined to terminal rams of various breeds that include Coopworth, East Friesian, Dorset, White Suffolk and Texel (Atkins, 1980). Robust knowledge is required on genetic parameters for the development of complex breeding objectives and selection indexes, comprehensive genetic evaluation of animals and the design of effective breeding programmes (Safari and Fogarty, 2003). Fogarty et al. (2003) and Safari et al. (2005) highlighted the lack of accurate estimates of correlations between different traits. This study aims at filling this knowledge gap in wool comfort factor by investigating both genetic and non-genetic sources of variation in pasture fed versus protein-supplemented sheep and associations with spinning fineness, fiber diameter and wool curvature.

The impact of nutrition on the growth of wool has been studied, with periods of poor pasture growth or quality resulting in reduction in total growth per animal (Hyder et al., 2002). There is a relationship between nutrient intake and product output in that farm animals such as pasture-fed (either green pasture or conserved feed) and protein- supplemented (such as canola and lupins) sheep can have marked variation in growth and the quality of wool or meat produced. Sheep are supplemented to maximize the rate of growth or production, to rectify dietary deficiency, or to compensate for insufficient or poor-quality pasture (Hinton, 2007). It is well recognized that methionine and cysteine are the primary limiting amino acids for wool production in sheep (Liu and Masters, 2000). Hynd and Masters (2002) showed that an increase in essential amino acids such as cysteine and methionine may increase fiber output (increased diameter and length). Canola and lupins contain substantial amounts of these amino acids, thus, feeding sheep on adequate amounts of protein-rich supplements like canola and lupins could potentially pay dividends in terms of wool growth and yield.

Feeding supplementary grains, manufactured feed or conserved fodder to grazing stock is relatively expensive, often wasteful and time consuming, although in some cases, it is necessary and achieves economic returns (Hinton, 2007). However, published information on wool comfort factor at the farmgate level in crossbred sheep remains scanty, particularly with regard to interactions between sire genetics and nutrition. In this study, we tested the following hypotheses:

1. Wool comfort factor will not vary between grazing and protein-supplemented sheep.
2. Wool comfort factor in crossbred sheep will be significantly influenced by sire breed, gender, level of protein supplementation and their second-order interactions.
3. Wool comfort factor will be reliably predicted from other wool quality traits.

Therefore, our primary objective was to investigate the effects of sire genetics, nutrition, level and type of supplementation, gender and their interactions on wool comfort factor (CF) and its correlation with other wool quality traits in crossbred sheep either grazing or supplemented with dietary protein. The secondary objective was to assess the prediction accuracy of wool comfort factor from other wool quality traits in crossbred sheep.

2. MATERIALS AND METHODS

2.1 Experimental Site

The data used in this investigation originated from a sheep crossbreeding experiment conducted in 2008 at the University of Tasmania Farm, Cambridge, whose preliminary findings have been published by Malau-Aduli et al. (2009a, 2009b, 2009c, 2009d, 2009e). Cambridge is situated approximately 18 km from Hobart City, Tasmania, Australia.

2.2 Animals, Experimental Design and Management

All animals and experimental procedures utilized in this study had the University of Tasmania Animal Ethics approval and were conducted in accordance with the 1993 Tasmanian Animal Welfare Act and the 2004 Australian Code of Practice for the Care and Use of Animals for Scientific Purposes. Texel, Coopworth, White Suffolk, East-Friesian and Dorset rams were joined with 500 Merino ewes at a mating ratio of 1:100 in individual paddocks. Five hundred of the crossbred progeny were raised on ryegrass pasture until weaning at 12 weeks of age and served as the grass-fed control treatment group. Forty of the weaners with an initial body weight range of 23-31 kg (average of 27 ± 3.2 kg), were randomly selected and assigned to 4 supplementary treatment groups of either lupins or canola and fed at either 1% or 2%of body weight for 6 consecutive weeks in a 5 × 2 × 2 x 2 factorial experimental design. Lambs were individually housed in 0.6mx1.2m metabolic crates. All control group and supplemented animals were fed a daily basal diet of barley, molasses-treated straw, mineral mix and had *ad libitum* access to water. The lambs were allowed 21 days of adjustment to feed prior to data collection. The daily routines included emptying of fecal collection trays, cleaning, weighing of fresh feed on offer and the previous day's residual. Body weight, body measurements and body condition score were monitored and recorded weekly.

2.3 Wool Testing

The sheep were shorn after 5-6 weeks of wool growth. A rib side wool sample was taken from each lamb using standard commercial shearing facilities. The greasy fleece weight minus the lock and bellies were recorded for every lamb. The wool samples were labeled and sent to the Australian Wool Testing Authority in Melbourne for analysis. The measured wool traits were comfort factor (CF), fiber diameter (FD), spinning fineness (SF), staple strength (SS), staple length (SL), curvature (CURV) and coefficient of variation (CV).

2.3 Statistical Analyses

The data were analyzed in SAS (2009) using MIXED models procedures (PROC MIXED) with sire fitted as a random effect, while sire breed, feed type, supplement, level of supplementation, gender and their interactions were fitted as fixed effects. PROC CORR (SAS, 2009) was used to compute the correlations between wool comfort factor and other wool traits. For the simple and multiple regression analyses, PROC REG (SAS, 2009) was used to derive prediction equations for comfort factor from other wool quality traits.

3. RESULTS

Results of multivariate analysis of variance to test for fixed effects and their interactions on wool quality traits are depicted in Table 1.

Table 1. Multivariate analysis of variance to test for fixed effects and interactions on wool quality traits (P-values).

Source	Comfort Factor	Fiber Diameter	Curvature	CV
Feed type (F)	0.0001***	0.0001***	NS	NS
Sex	0.0001***	0.0001***	NS	NS
Supplementation Level (L)	NS	0.0329*	NS	NS
Sire breed (SB)	0.0089**	0.0095**	NS	NS
Supplement (S)	0.0092**	0.0076**	0.0123*	0.0001***
Interactions				
FxSB	0.0009***	0.0005***	NS	NS
FxL	NS	NS	NS	NS
Sex x L	NS	NS	NS	NS
SB x L	0.0056**	NS	NS	0.002**
S x L	0.0043**	0.0063**	NS	NS
SB x S	0.0342*	0.0018**	NS	0.0347*
S x Sex	NS	NS	NS	NS
S x SB	NS	NS	NS	0.0001***

** Significant (p<0.05), ** highly significant (p<0.01), *** very highly significant (p<0.001). CV=Coefficient of variation of fiber diamet.er*

It was evident that all fixed effects significantly (P<0.05) influenced FD, while type of supplement influenced all the tested wool quality traits. Fibre curvature was not affected by any of the interactions. CF was highly influenced (P<0.01) by all fixed effects with the exception of level of supplementation and its interaction with feed type and sex, and the interactions between supplement and sex and supplement and sire breed.

Phenotypic correlations between CF and other wool traits are shown in Table 2. CF was highly negatively correlated with fiber diameter (-0.89) and spinning fineness (-0.95), moderately negatively correlated with CV (-0.27) and positively correlated with curvature (0.33). The highest positive correlation of 0.95 was observed between wool fiber diameter and spinning fineness.

Table 2. Correlations between comfort factor and other wool traits in crossbred sheep

	Comfort Factor	Fiber Diameter	Spinning Fineness	Curvature	CV
Comfort Factor		-0.89***	-0.95***	0.33**	-0.27*
Fiber Diameter	-0.89***		0.95***	-0.21*	0.09NS
Spinning Fineness	-0.95***	0.95***		-0.33**	0.12NS
Curvature	0.33**	0.09NS	-0.33**		-0.39***
CV	-0.27*	0.09NS	0.12NS	-0.33***	

*Level of significance: * significant (p<0.05), ** highly significant (p<0.01), *** very highly significant (p<0.001), NS=Non-significant, CV=Coefficient of variation of fiber diameter*

A comparison of grass-fed and grain-fed sheep in terms of comfort factor (CF) is depicted in Figure 1 where CF was significantly (P<0.05) higher in grass-fed (93.1±0.3%) than their grain-fed (85.9±1.1%) counterparts under the same management environment.

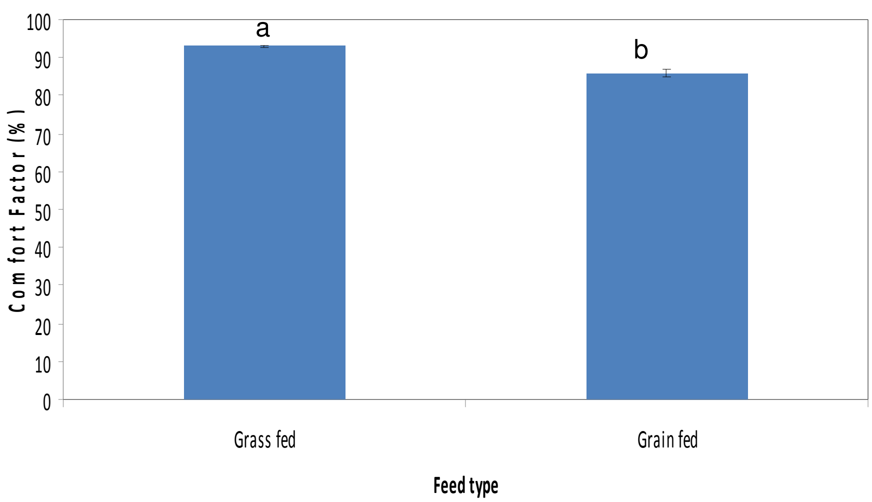

Figure 1: Effect of feed type on comfort factor in crossbred sheep.

Gender variation in wool CF is portrayed in Figure 2 where it was demonstrated that wethers (males) had significantly (P<0.01) higher CF (89.4±1.5%) than ewes (females) (82.9±1.4%) within the same crossbred sheep management system.

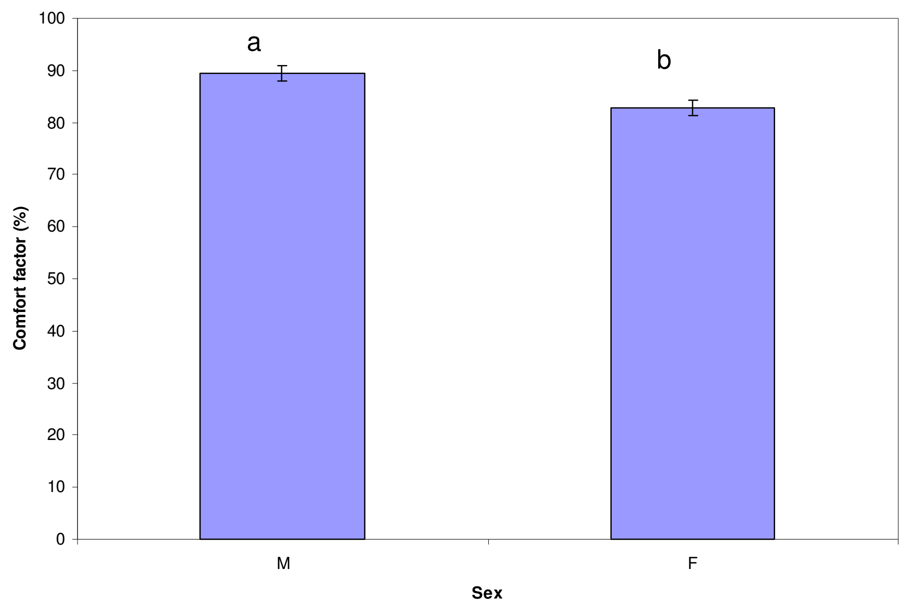

Figure 2. Effect of sex on wool comfort factor in crossbred sheep.

The influence of canola and lupin supplements on CF and CURV is shown in Figure 3. It indicates that there were no significant differences between crossbred lambs fed on canola and lupins in terms of CF (87.5.1±1.2% vs 84.1±0.1.9%) and CURV (71.9±1.5% vs 70.6±1.7%), respectively.

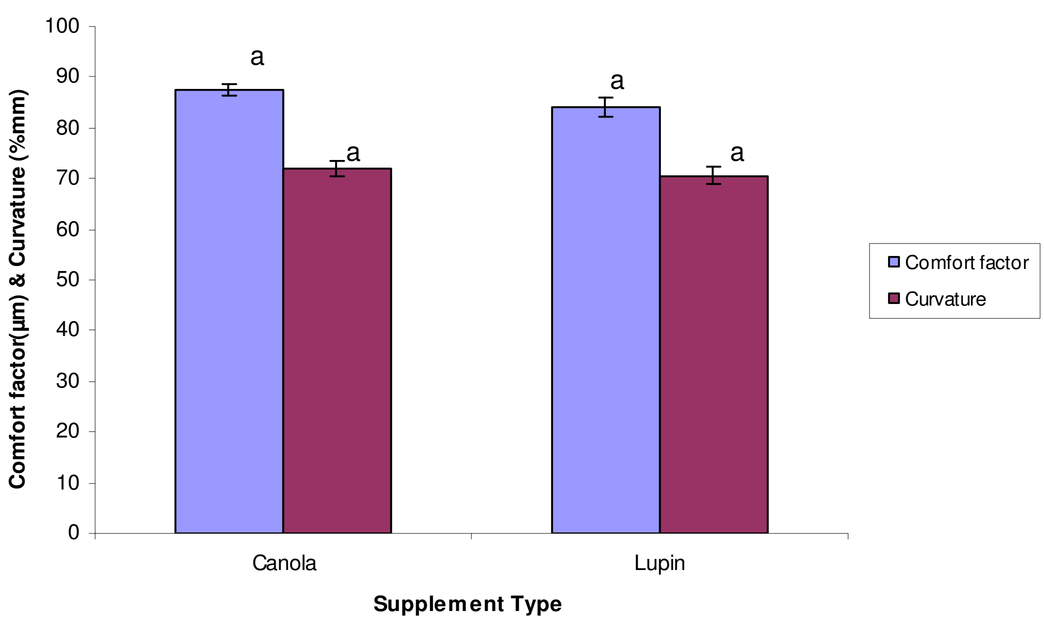

Figure 3. Effect of supplement type on comfort factor and fiber wool curvature.

When the crossbreds were fed at 1% of BW, it resulted in higher comfort factor (88±1.6%) compared with 2% BW (83.7±1.5%) as shown in Figure 4.

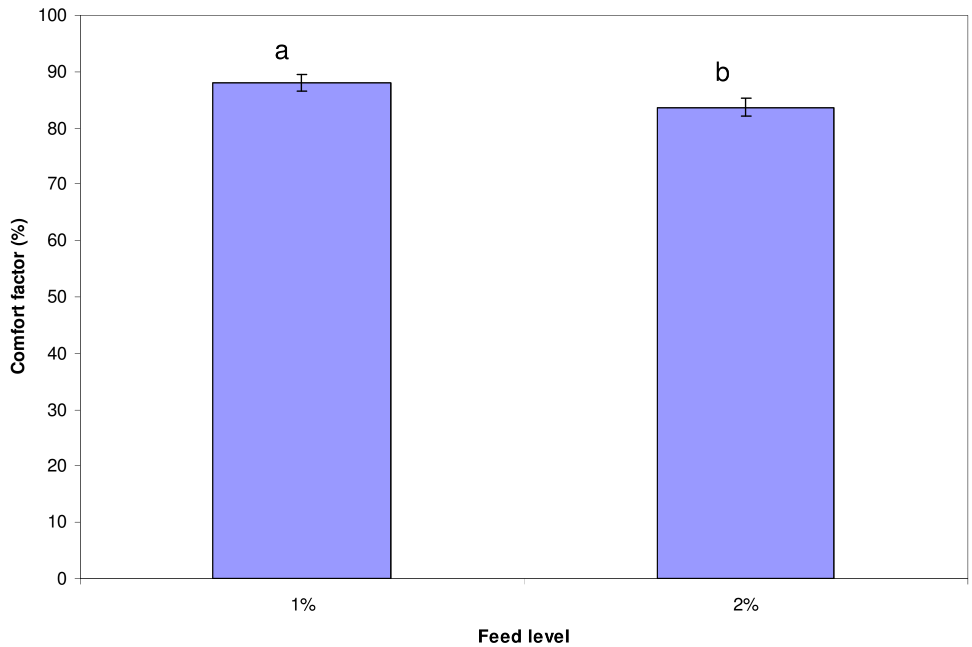

Figure 4. The effect of supplementation level on comfort factor in crossbred sheep.

It can be discerned from Figure 5 that White Suffolk crosses had the highest CF when fed on both grass and grain (94.3% and 90.1% respectively), closely followed by Dorset crosses fed on grass (CF= 94.4%) and grain (85.5%). Coopworth crosses had a CF of 90.8% when grain-fed. East-Friesian and Dorset crosses had the lowest CF (90.5% and 89.99%) when fed on both grass and grain (81.5% and 84.9% respectively).

Figure 5. Effect of sire breed on comfort factor (µm) in crossbred sheep.

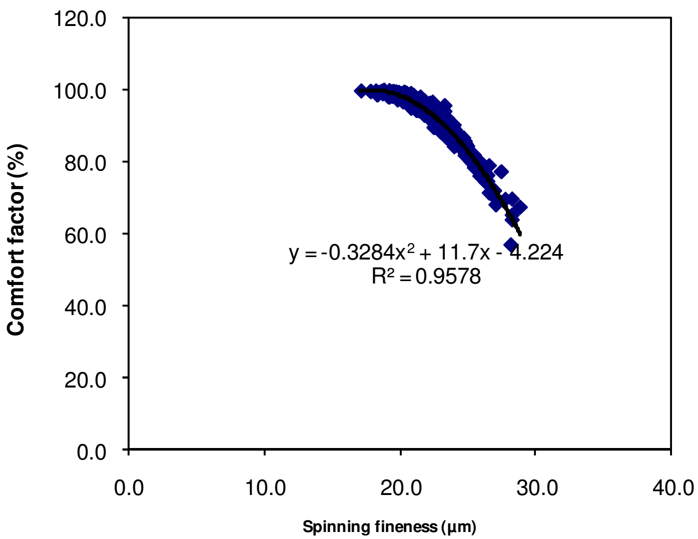

Figure 6. Polynomial regression equation and accuracy of prediction of comfort factor from spinning fineness

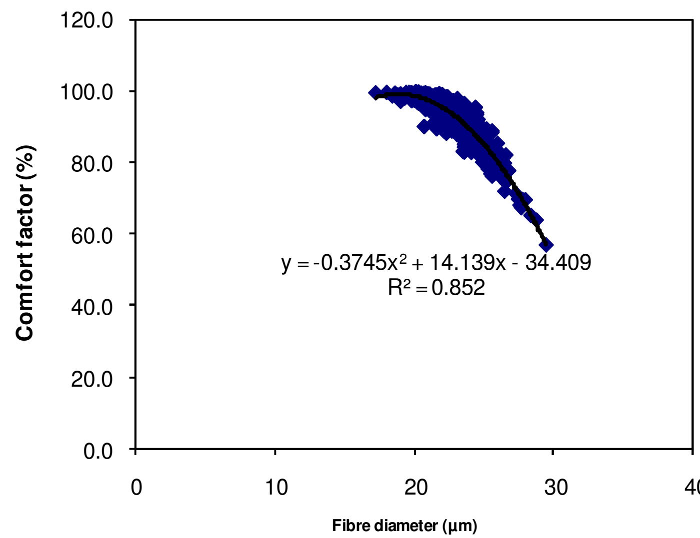

Figure 7. Polynomial regression equation and accuracy of prediction of comfort factor from fiber diameter

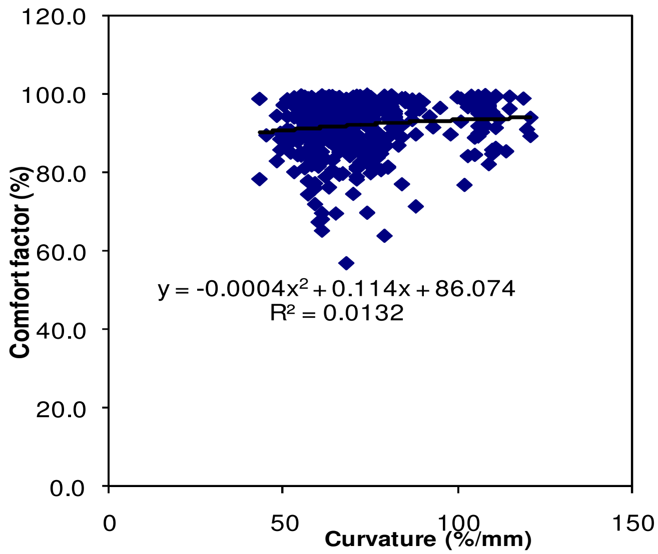

Figure 8. Polynomial regression equations and accuracy of prediction of comfort factor from curvature.

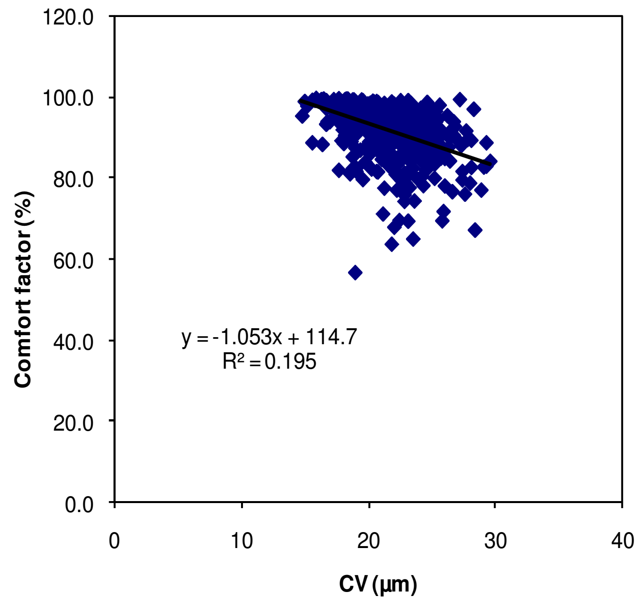

Figure 9. Simple regression equations and accuracy of prediction of comfort factor from coefficient of variation

Figures 6-9 depict the relationships and accuracies of prediction (R^2) of CF from spinning fineness, FD, CURV and CV, the most accurate predictors being spinning fineness and FD.

Comfort factor can be effectively predicted from spinning fineness and fiber diameter with R^2 0.9578 and 0.852 respectively. Coefficient of variation (CV) and curvature were not accurate predictors of comfort factor (R^2=0.0132 and 0.1957 respectively). In summary, only spinning fineness and fiber diameter were the main wool traits that accurately predicted wool comfort factor.

4. DISCUSSION

4.1 Effect of Sire Breed

Land (1978) found that the differences between and within breeds could be due to the differences in sire breed maturity as well as the onset puberty that was inherited by the progeny. Casas et al. (2005) evaluated Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep and found that the interactions between sire breeds were often due to changes in ranking as well as magnitude, indicating the importance of sire breed selection and superiority of individual rams. Thus, breed diversity is a valuable resource that can be managed to exploit individual and paternal genetic effects by using sire breeds to complement characteristics of crossbred ewes in terminal crossbreeding systems as a means of efficiently improving commercial lamb and wool production (Casas et al., 2005, Scales et al., 2000). Therefore, a comprehensive appraisal of breeds is critical in providing valuable information that determines the appropriate use of breeds in crossbreeding systems to meet specific production environments and marketing goals (Casas et al., 2005).

Coopworth, Texel, Dorset and White Suffolk are traditional meat breeds that can be crossed with Merino ewes to improve both wool and meat quality. This study found that grazing lambs sired by White Suffolk and Dorset rams had the highest comfort factor (CF) compared with their counterparts sired by Coopworth, East Friesian and Texel rams. This could possibly be a reflection of the differences in scale and magnitude of hybrid vigour in these sire breeds. Scales et al. (2000) found that Dorset and Suffolk crossbred lambs grew at a faster rate compared to other breeds. This trend in body growth probably contributed to the observed variation in wool CF. Lower CF in lambs sired by Texel can be attributed to the fact that Texel sheep are well known for their ability to produce progeny with lean carcasses (Scales et al., 2000), therefore, Texel seemed to channel the partitioning of their absorbed nutrients towards muscle growth rather than wool fineness, hence the lower CF.

CF was significantly higher in crossbred lambs raised on grass than their grain-fed counterparts in this study. This variation in CF could probably be due to the high protein levels in lupins and canola. It has been shown that methionine and cysteine are the primary limiting amino acids associated with wool synthesis (Liu and Masters, 2000). It is likely that these amino acids were preferentially partitioned towards favoring faster growth and meat production at the expense of fine wool synthesis in the crossbred progeny. However, White Suffolk and Dorset sired lambs fed on grass had lower fiber diameter, thus finer wool compared with their counterparts sired by other breeds. This was consistent with the higher CF found in these breeds because the finer the wool, the higher the wool CF. Therefore, White Suffolk and Dorset rams would best serve the dual purpose of meat production and good quality wool when managed under conventional pasture-based sheep management systems (AWI, 2009). This trend was also evident when the lambs were fed with supplements since White Suffolk and Coopworth had comparatively lower fiber diameter than other breeds. This does not in any way imply that the other breeds serve no purpose, but that they can be more utilized specifically for meat production as prime lambs.

Wool fiber curvature was higher in White Suffolk-sired lambs in both grass and grain-fed management styles than in lambs sired by other breeds. High wool fiber curvature tends to give slightly less even yarns and the fabric contracts more when wet. However, in this study, our values fall within the medium curvature range which lies between 60-90 degrees/mm (AWI 2009). However, fiber curvature is not a stable property and if the wool has not been chemically treated, most of the crimp present in the greasy wool can be recovered by relaxation in warm water (Casas et al., 2005).

The effect of sire genetics on the coefficient of variation of fiber diameter (CV) showed significant variation in lambs sired by East-Friesian and Dorset breeds in both grain and grass-fed nutrition. The lower the CV, the more uniform the diameters of individual fibers within the fleece (DEEPI, 2005). A previous study had shown that including CV in the breeding objectives can give less attention to traits that have a direct economic value such as fiber diameter and fleece weight (DEEPI, 2005). The critical time to include CV in a selection program is when improvements in staple strength are required because staple strength and CV are closely genetically related (AWI 2009). Therefore, CV can be used to identify sheep with genetically higher staple strength. Although CV is heritable, it is a slow process to achieve responses when compared to selection for average fiber diameter (AWI 2009). Research has shown that wool that has a five per cent lower CV processes to the equivalent of wool that is one micron finer (AWI 2009).

4.2. Supplement Type and Level of Supplementation

Canola and lupins are the dominant supplementary feed for sheep in Australia. This study has shown no significant influence of either canola or lupin supplementation on wool CF, fiber diameter, fiber curvature and CV. White et al. (2000) indicated that farmers generally believe that lupins are superior to other cereal grains for wool growth because of their high protein content, but there is no experimental evidence supporting this assertion. It is important to bear in mind that the physiological status and metabolic response to supplementation by sheep may have varying effects on wool production and quality. White et al. (2000) suggested that increasing ruminal propionate can improve protein utilization that spares the utilization of amino acids for glucose precursors. Liu and Masters (2000) found that increasing the quantity of dietary methionine and cysteine resulted in higher body and wool growth, higher turn-over rate of protein and oxidation rates that did not have detrimental effects on wool growth. All these physiological and metabolic responses must have been similar in sheep supplemented with canola or lupins. It had also been demonstrated that canola or lupins promote wool growth with variable degrees of metabolisable protein that is associated with improved sulphur amino acid content (White et al., 2000, Liu and Masters 2000). However, the previous studies were based on pure Merino ewes, while in this study, we utilized crossbred sheep.

Although there was no statistical difference between sheep supplemented with canola and lupins in CF, fiber diameter, fiber curvature and coefficient of variation of fiber diameter, the effect of supplementation level showed that when crossbred sheep were fed at 1% of their BW, there was a higher CF, lower fiber diameter and higher curvature compared to when they were fed at 2% of their BW. The level of nutrition affects wool synthesis and production efficiency. This trend was consistent with the results of Naqvi and Rai (1990) and Weston (1965) who observed a similar trend in high and low wool producing groups of Merino sheep at restricted and *ad libitum* feeding. Moran (1970), Saville and Robards (1972) and Robards et al. (1976) have found inverse relationships between efficiency and decreasing levels of feeding. The efficiency of feed conversion to wool increased with decreasing levels of feeding and sire breed differences were also significant. Any differences between canola and lupins could have been due to variation in partitioning of energy between wool and meat production (Naqvi and Rai, 1990) that resulted in finer wool fibers, lower fiber diameter, shorter wool length and more crimps (Naqvi and Rai, 1990). The wool fibers became fine at low levels of intake amongst the crossbred lambs. This fineness of the wool under feed restriction may be attributed to an effective feed conversion to useable form. Varying feeding levels affected staple strength and percent reduction in staple length. It may thus be inferred in our present study that feeding at 1%BW increased CF and reduced wool fiber diameter.

The level of nutrition may affect fiber diameter because overfed animals produce higher micron values than those on a maintenance diet. This does not mean that animals should be underfed to produce finer wool fibers. An unsound or unhealthy animal is a risk in a breeding program regardless of its fiber diameter. Poorly fed sheep also produce wool with weak staples. Moreover, underfeeding causes significant negative side effects, such as lowered fertility, lower birth weights, and higher mortality rates in young ones (McColl, 2009). The safer course is to maintain sheep on a thrifty but nutritious diet that maintains a healthy body condition to produce fiber that lives up to its genetic potential, by following the animal husbandry practices suitable for the farm's location. Therefore, from our results, the producers can feed their flock at 1% of their BW which is cheaper than at 2% of their BW. However, care should be taken so that the flock is not deprived of feed which could result in finer wool but with weak staple strength and short fiber length.

4.3 Effect of Sex on Wool Quality Traits

Although McColl (2009) showed that males frequently possess a higher micron value than females, the results in this study showed that females had significantly coarser fiber diameters (25±0.3µm) compared to their male counterparts (23.5±0.4µm). The differences in sex can be purely due to the differences in follicle growth rates that possibly triggered variation in hormonal profiles. Rams are known to have higher follicle numbers than ewes because they are heavier and thus have a greater surface area for follicle initiation (Pitchford 1992; McColl, 2009). Pitchford (1992) reported that rams would be expected to have higher fiber diameter than ewes because they have more surface area from which to produce wool and lower follicle density resulting in larger fibers. McColl (2009) found that sex, age and nutrition all affected wool fiber diameter, and as the animal matured, its fibers tended to have higher or coarser micron value.

Pitchford (1992) suggested that rams partitioned a greater proportion of available nutrients toward growth than ewes, which may be due to hormonal effects which impact on metabolic pathways. Wethers also have less testosterone levels than intact rams and this can have an effect on CF and fiber diameter. Heterosis may also have an impact on the progeny because hybrid vigour always has good muscle growth effect, but may have deleterious effects on wool quality, particularly wool comfort factor (CF) and fiber diameter. Maternal effects however were generally not important in our study because only Merino ewes were used across board in our crossbreeding. The differences in CF in these sires stemmed from individual heterosis that increased mature weight. Pitchford (1992) found that increasing mature weight increased available area for follicle initiation resulting in greater number of follicles.

CF can be reliably predicted from spinning fineness and fiber diameter with higher precision accuracies (R^2=0.9578 and R^2=0.852, respectively). On the other hand, fiber curvature (R^2=0.0132) and coefficient of variation of fiber diameter (R^2=0.1957) were unreliable predictors of CF. This is consistent with the study conducted by Naylor and Phillips (1995) that suggested that an absolute skin comfort factor can be predicted from fiber and fabric parameters. CSIRO found that a fabric with more than 5 per cent of wool fibers over 30 microns in diameter is uncomfortably-prickly (AWI 2009). Therefore, decreasing fiber diameter is the most effective way to reduce the level of coarse fiber content. Reducing CV will also reduce the number of coarse fibers, which improves CF in medium and stronger type wool.

4.4. Grass-Fed versus Grain-Fed Nutrition

Pasture grasses are the predominant feed used to raise livestock in Australia. Pasture quality rather than quantity, is the main factor that drives the productivity of livestock. However, supplements are occasionally involved in feeding farm animals to augment the quantity of existing feed or during feed-gaps. Feed intake is determined by the health, age, size, sex and physiological status of an animal. Feed can be in the form of fresh grass, hay, silage or fodder crop. In this study, sheep fed on grass produced wool with higher CF and lower fiber diameter than those fed on grain. The differences between grass-fed and protein-supplemented sheep could be attributed to different ways in which protein degradation in canola and lupin occurs in the rumen. Diets containing canola meal had been shown to increase wool growth and decrease fiber diameter (Masters and Mata 1996). This is because canola is partially protected from rumen degradation, thus making it escape biohydrogenation with the essential amino acids going into wool synthesis and growth. Due to the effect of crossbreeding, there may be insufficient microbial protein production relative to energy during feed degradation and/or that the microbial protein produced has amino acids composition that does not match the requirements of the ewes (Masters and Mata 1996) or perhaps led to a proliferation of excess amino acids that got channeled into meat production.

Since nutrition is a limiting factor in wool production, canola and lupins are known to have considerable amino acids levels which increased the proliferation of both primary and secondary wool follicles, thus resulting in coarser wool unlike grass-fed lambs. Coarser wool always has higher microns and lower comfort factor, an observation supported by Masters and Mata (1996) who found that wool growth and fiber diameter were significantly increased when ewes were fed on canola and lupins. Liu and Masters (2000) found that the requirements of methionine and cysteine for wool production had not been well qualified because there were two problems associated with the adaptation and use of the conventional metabolisable protein requirements system. This was contrary to White et al. (2000) who reported that lupins were superior to other cereal grains for wool growth because of their higher protein content. This could determine the extent of microbial degradation of protein supplements in the rumen as an indication of what proportion of the feed protein is available for microbial metabolism. This by difference would determine the un-degraded protein that could become available to the sheep after enzymatic digestion for both muscle and wool. It is well established that crossbreds often perform at a higher level than the average performance of the purebreds that make up the crossbred (Thompson and Hynd 1998). This increased performance of crossbreds (hybrid vigour or heterosis) can partly contribute to lower CF and higher fiber diameter.

5. IMPLICATIONS OF FINDINGS

The findings in this study showed that White Suffolk and Dorset rams produced progeny with the highest CF compared to other terminal sires, especially when the crossbreds were fed on grass. This provides an insight to what to look for when the producer chooses a ram for breeding in dual purpose sheep production systems. These results can potentially be incorporated into LAMBPLAN to rank these terminal sires based on their comfort factor. Therefore, CF can provide a benchmarking system that allows a producer to improve wool quality as well as meat through crossbreeding. This study found that CF can be reliably predicted from spinning fineness and wool fiber diameter. Since supplementing crossbred sheep during feed shortages is a vital feeding strategy, the results showed that it can be cheaper to feed sheep at 1% of their BW and still obtain wool of reasonable quality rather than at 2% of their BW which can incur higher production cost. Whether one supplements crossbred sheep with canola or lupins, our results indicated that there were no significant differences in wool quality. Therefore, during periods of feed shortages, supplementing with either canola or lupins will not have a deleterious effect on CF.

6. CONCLUSION

Improving the performance of the production system by crossing complementary breeds is one of the benefits of crossbreeding. This is because crossbreeding enhances the effectiveness of the dual-purpose sheep production system and takes advantage of heterosis using Merino ewes and terminal sires to produce prime lambs. In this study, the White Suffolk x Merino and Dorset x Merino crosses were the overall best performing sheep because of their comparatively higher comfort factor and lower fiber diameter than the other crossbreds when they were fed on grass. However, White Suffolk and Coopworth sired progeny gave higher comfort factor when they were supplemented with canola or lupins. Fiber diameter was lower when sheep were fed on grass. This emphasises the importance of maintaining crossbred flock on adequate pasture. Fiber curvature was higher in grass fed than grain supplemented sheep. However, it was within the medium curvature range. Therefore, the hypothesis that wool comfort factor will not vary between grazing and supplemented sheep should be rejected. However, the second hypothesis should be accepted because sire breed, gender and level of supplementation significantly influenced wool comfort factor. It was also demonstrated in this study that CF was higher when the sheep were fed at 1% of their BW, thus resulting in lower fiber diameter. It is therefore cheaper to feed the flock at 1% of the body weight. The strong relationships between wool comfort factor and other wool quality traits enabled a reliable prediction of wool comfort factor from spinning fineness and fiber diameter, hence an acceptance of the third hypothesis.

ACKNOWLEDGEMENTS

This study was funded by research grants and scholarships from the University of Tasmania (UTAS), the Australian Wool Education Trust (AWET), and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Food Futures National Flagship. The authors are grateful to UTAS, AWET and CSIRO.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Atkins, K.D. (1980). The comparative productivity of five ewe breeds. Aust. J. Agric. Anim. Husb., 20, 280-287.

AWI. (2009). Australia Wool and Innovation. Wool production, coefficient of variation of fiber diameter. www.awi.org.au. Viewed on March 26, 2010.

Bardsley, P. (1994). The collapse of the Australian wool reserve price scheme. Econ. J., 104, 1087-1105.

Casas, E., Freking, B.A., Leymaster, K.A. (2005). Evaluation of Dorset, Finnsheep, Romanov, Texel, and Montadale breeds of sheep: V. Reproduction of F_1 ewes in spring mating seasons. J. Anim. Sci., 83, 2743-2751.

DEEPI (2005). Department of Employment, Economic Development and Primary Innovation. Wool production, coefficient of variation of fiber diameter (CVFD). http://www.dpi.qld.gov.au/home.htm, viewed on 14th October 2010.

Fogarty, N.M., Brash, L.D., Gilmour, A.R. (2003). Genetic parameters for reproduction and lamb production and their components and liveweight, fat depth and wool production in Hyfer sheep. Aust. J. Agric. Res., 45, 443-57.

Fogarty, N.M., Safari, E., Gilmour, A.R., Ingham, V.M., Atkins, K.D., Mortimer, S.I., Swan, A.A., Brien, F.D., Greeff, J.C., van der Werf, J.H.J. (2006). Wool and meat genetics - the joint possibilities. Intl. J. Sheep Wool Sci., 54, *22-27.*

Hinton, D.G. (2007). Supplementary feeding of sheep and beef cattle. Second Edition, www.landlinks.com, Landlinks Press, Melbourne, Australia, 104pp. Viewed on Jan 7, 2010.

Hyder, M.W., Thompson, A.N., Doyle, P.T., Tanaka, K. (2002). The responses of broad- and fine-wool Merino wethers to differential grazing of annual pastures during spring. Aust. J. Expt. Agric., 42, 117-128.

Hynd, P. I., Masters, D.G. (2002). Nutrition and wool growth. In: M. Freer and H. Dove (Editors) Sheep Nutrition. pp 165-188. CABI Publishing, Wallingford, Oxfordshire, UK.

Land, R.B. (1978). Reproduction in young sheep: Some genetic and environmental sources of variation. J. Reprod. Fert., 52, 427-436.

Liu, S.M., Masters, D.G. (2000). Quantitative analysis of methionine and cysteine requirements for wool production of sheep. Anim. Sci., 71, 175-185.

Malau-Aduli, A.E.O., Ranson, C.F., Bignell, C.W. (2009a). Wool quality and growth traits of Tasmania pasture-fed crossbred lambs and relationships with plasma metabolites. J. Anim. Sci., 87, 499.

Malau-Aduli, A.E.O., Walker, R.E., Bignell. C.W. (2009b). Prediction of wool fibre diameter from protein and metabolisable energy digestibility coefficients in crossbred sheep. J. Anim. Sci., 86, 498.

Malau-Aduli, A.E.O., Sykes, J.M., Bignell, C.W. (2009c). Influence of lupins and canola supplements on plasma amino acids, wool fibre diameter and liveweight in generally divergent first cross Merino lambs. In: Proceedings of The World Congress on Oils and Fats and 28th International Society for Fats Research Congress, 27-30 September 2009, Convention and Exhibition Centre, Sydney, Australia, 28, 63.

Malau-Aduli, A.E.O., Walker, R.E., Bignell, C.W. (2009d). Variation in sire genetics is an irrelevant determinant of digestibility in supplemented crossbred sheep. In: Y. Chilliard, F. Glasser, Y. Faulconnier, F. Bocquier, I. Veissier, M. Doreau (Editors), Wageningen Academic Publishers, The Netherlands. Proceedings of the XIth International Symposium on Ruminant Physiology, 6-9 September 2009, Clermont-Ferrand, France, 11, 278-279.

Malau-Aduli, A.E.O., Walker, R.E., Ranson, C.F., Sykes, J.M., Bignell, C.W. (2009e). Nutrition-genetics interactions in nutrient utilisation of canola and lupins by Australian sheep: Prediction of wool fibre diameter. In: D. Sauvant (Editor) Proceedings of the 7th International Workshop on Modelling Nutrition, Digestion and Utilization in Farm Animals, 10-12 September 2009, AgroParisTech, Paris, France, 7, 50.

Masters, D.G., Mata, G. (1996). Responses to feeding canola meal and lupin seed to pregnant, lactating, and dry ewes. Aust. J. Agric. Res., 47, 1291-303.

McColl, A. (2009). Understanding microns, quality breeding stock and companion animals. www.ramsay-farms.com. Viewed on Jan 4, 2010,

Moran, J.B. (1970). Effect of level of feed intake on wool growth rate and wool characteristics. J. Aust. Inst. Agric. Sci., 36, 40-41.

Naqvi, S.M.K., Rai, A.K. (1990). Effect of nutritional stress on wool yield, characteristics and efficiency of feed conversion to wool. J. Livest. Res. Rural Dev., 2, 56-63.

Pitchford, W.S. (1992). Effect of crossbreeding on components of hogget wool production. Aust. J. Agric. Res., 43, 1417-1427.

Robards, C.E., Davis, C.H., Saville, D.G. (1976). Skin folds and Merino breeding. 9. Efficiency to conversion of food to wool. Aust. J. Expt. Agric. Anim. Husb., 16,361-366.

Rowe, J.B. (2010). The Australian sheep industry – undergoing transformation. Anim. Prod. Sci., 50, 991-997.

Safari, E., Fogarty, N.M., Gilmour, A.R. (2005). A review of genetic parameter estimates for wool, growth, meat and reproduction traits in sheep. Livest. Prod. Sci., 92, 271-289.

Safari, A., Fogarty, N.M. (2003). Genetic parameters for sheep production traits. Estimates from the literature. NSW Department of Agriculture and Australian Sheep Industry CRC, Orange, New South Wales, Australia.

SAS (2009) Statistical Analysis System (North Carolina, USA).

Saville, D.G., Robards, C.E. (1972). Efficiency of conversion of food to wool in selected and unselected Merino types. Aust. J. Agric. Res., 23, 117-130.

Scales, G.H., Bray, A.R., Baird, D.B., O' Connell, D., Knight, T.L. (2000). Effect of sire breed on growth, carcass, and wool characteristics of lambs born to merino ewes in New Zealand. New Zealand J. Agric. Res., 43, 93-100.

Weston, R.H. (1965). The efficiency of wool production of grazing Merino sheep. Division of Animal Health and Production, CSIRO, Sheep Laboratory, Prospect, NSW, Australia.

White, C.L., Young, P., Philips, N., Rodehutscord, M. (2000). The effect of the dietary protein source and protected methionine (lactet) on wool growth and microbial protein synthesis in Merino wethers. Aust. J. Agric. Res., 51, 173-183.