Sheep CRC Conference Proceedings

Document ID:	SheepCRC_22_6
Title:	Extreme wool production - implications for fitness
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Key words:	sheep; wool; robustness; selection

This paper was presented at the Sheep CRC Conference 'Wool Meets Meat' held in Orange, NSW in 2006. The paper should be cited as:

Adams, N.R.; Hatcher, S.; Schlink, A.C. (2006) *Extreme wool production - implications for fitness* in 'Wool Meets Meat' (Editors P. Cronje, D. Maxwell) Sheep CRC pp 44-48.

Extreme wool production—implications for fitness

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Abstract

The research reported here examined factors that affect the production of high-value fleeces grown in harsh environments with particular emphasis on how wool production affects fitness of sheep. Data were derived from genetic resource flocks in New South Wales and Western Australia. Sheep with high genetic values for clean fleece weight had less energy reserves than those with low genetic values for clean fleece weight. The small energy reserves of sheep with high genetic values for clean fleece weight were reflected in lower fatness and lower plasma concentrations of glucose and insulin, the extent of which were sufficient to reduce reproductive turnoff. Selection for low fibre-diameter does not exert these effects, but wool yield is associated with fatness. Yield is important to achieve price premiums for fine wool grown in dusty environments, but the dust content of wool with low dust penetration is surprisingly high. Furthermore, the current method of assessment of dust content based on dust penetration does not reflect the ease of processing. These results indicate that fitness characteristics such as reproduction and fatness should be considered in the breeding objective when selecting for increased fleece weight in harsh environments.

Industry concerns about selection and fitness

Many Merino breeders are concerned that genetic selection for high wool productivity may reduce the fitness of sheep, i.e., their capacity to survive, thrive and reproduce under harsh circumstances (Kaine and Niall, 2001). Cloete et al. (2002) reported a negative genetic correlation between high clean fleece weight (CFW), corrected for liveweight, and the total weight of lambs weaned. Some breeders subsequently reduced the emphasis on CFW in their breeding objectives, a practice that may limit progress in the wool industry. Other woolgrowers are concerned about achieving price premiums for fine wool grown in dusty environments. In this communication, we review the scientific evidence for these concerns.

Genetic associations between traits

Genetic selection for one trait may result in a response in another trait. Genetic correlations provide information on the magnitude of these associated responses.

Selection for high fleece weight reduces energy reserves

CFW has small negative genetic correlations with subcutaneous fat depth and weaning rate (less than –0.2; Safari et al., 2005). It is estimated that sheep with genetically high fleece weights will be less able to withstand nutritional stress.

Research conducted by the New South Wales Department of Primary Industries (NSW DPI) revealed a significant inverse relationship ($P < 0.001$) between estimated breeding value (EBV) for CFW and fat depth (measured by ultrasound at the GR site) in a flock of sheep with EBVs for CFW ranging from 3.55 kg to 5.02 kg. The relationship between CFW and fat depth was much stronger than that between CFR and liveweight ($P < 0.05$). Similarly, Adams et al. (2005) measured energy reserves in two groups of sheep that differed in EBV for CFW by 0.75 kg. Both groups had similar liveweight (48.8 kg and 49.1 kg for low and high CFW sheep, respectively) and were in relatively poor body condition after grazing dry autumn pasture in a winter rainfall region. The high CFW group had less body fat than the low CFW group (8.9 kg vs. 11.1 kg, $P < 0.01$). The sheep were then fed at a level that just exceeded maintenance energy requirements. The high CFW sheep had lower plasma concentrations of glucose, insulin and insulin-like growth factor-1 ($P < 0.05$) and higher plasma concentrations of growth hormone ($P < 0.001$) than the low CFW sheep. All of these measurements indicate that the nutritional status of the high CFW sheep was lower than that of the low CFW sheep. A similar decrease in body fat content and glucose and insulin concentrations caused by under-feeding would reduce lamb marking by at least 10% through decreased conception and lamb survival (Adams et al., 2005). Thus, lower reproduction rates of high CFW sheep compared to low CFW sheep are likely to be a consequence of low energy reserves of high CFW sheep.

If feed were to be restricted, the high CFW sheep described in this study would have fewer reserves to draw on. Our calculations indicate that the low CFW sheep would have to loose 100 g/d liveweight for one month for their body energy content to equal that of the high CFW sheep. Furthermore, feed intake of high CFW sheep was 9% greater than that of low CFW sheep, partly because high CFW sheep had a greater proportion of lean tissue. Similarly, the NSW DPI found that high CFW sheep consume more pasture than low CFW sheep ($P < 0.001$). The difference in absolute intake (kg) was small. Differences in intake were non-significant when expressed per kg liveweight, but statistically significant ($P < 0.01$) when expressed per kg of metabolic liveweight (liveweight $^{0.75}$). The balance between higher feed intakes and lower energy reserves of high CFW sheep may be important during droughts or when sheep are fed poor quality pasture or stubble. This may have particular significance for high CFW breeding ewes during pregnancy and lactation if the increased intake does not adequately compensate for the demand that fetal growth or milk production places on their limited energy reserves.

High CFW relative to liveweight may also impair muscle glycogen metabolism sufficiently to affect meat quality. Thomson (2004) studied two groups of rams that differed in EBV for CFW by 0.3 kg but had similar liveweight. The sheep were run on dry annual pastures and had similar concentrations of glycogen in biopsies of the *m. semimembranosus* at the beginning of the experiment. However, muscle glycogen content decreased to a greater extent ($P < 0.05$) after 2 h of strenuous exercise in rams with high EBVs for fleece weight than in those with low EBVs for fleece weight. As the concentration of glycogen in muscle at slaughter is a major determinant of the ultimate pH of muscle, this finding indicates that selection for high fleece weight contributes to the increased incidence of dry, dark-cutting meat in Merinos.

A study examining the effects of CFW and level of nutrition during pregnancy and lactation on the liveweight and fat score of breeding ewes and subsequent meat quality of their progeny is currently underway at Cowra Research Station as part of a Master's degree project funded by the Sheep CRC.

Effect of selection for fibre diameter on fitness remains unresolved

Fibre diameter has a small, positive genetic correlation with liveweight and fatness (< 0.2; Safari et al., 2005), but no other genetic associations between fibre diameter and energy metabolism have been described. For example, Adams et al. (2005) found no differences in fatness or concentrations of glucose or insulin in groups of 20 sheep that differed in EBV for fibre diameter by 2 µm. Similarly, the NSW DPI study did not detect a significant relationship between EBV for fibre diameter (range: 17.7–21.8 µm) and ultrasonic fat depth at the GR site within a group of 104 Merino ewes. Low fibre-diameter may be associated with reduced conception rates and poor maternal ability (Adams and Cronjé, 2003). However, twinning rate, which is greatly affected by a reduced supply of energy, appears to be unaffected by fibre diameter.

Effects of selection for staple strength on fitness not fully understood

The effects of genetic selection for staple strength on metabolism are not fully understood. High staple-strength sheep have a greater proportion of lean tissue in spring than low staple-strength sheep, but this difference was not observed after liveweight loss in the subsequent autumn season (Adams et al., 2000). Both wool growth and muscle protein synthesis respond less to dietary intake of nutrients in high staple strength sheep than in low staple strength sheep, and this may affect body composition.

Selection for wool yield decreases carcass fat and may affect fitness

Selection for greasy fleece weight often results in poorer yield because there is a small negative genetic correlation between these attributes (–0.14; Safari et al., 2005). Wool from sheep selected for greasy fleece weight may appear to have low dust content when assessed by the dust penetration method, but such fleeces contain high amounts of dust in the tip. This may reduce the efficiency of the scouring process. Yield affects price discounts for fine wool grown in the cereal zone, but selection for wool yield also affects body fatness and consequently, fitness.

The use of dust penetration as an indicator of dust content for classing of sheep has resulted in increased wax contents of fleeces because of a strong negative genetic correlation (–0.62) between dust penetration and wax content (Dowling et al., 2005). Genetic correlations indicate that selection for CFW rather than for greasy fleece weight should increase yield and reduce dust content, although dust penetration may increase.

Reduced wax content may enhance the ease of processing of wool. Westmoreland (unpublished) found that low-yielding wool with high wax content was difficult to scour using conventional aqueous detergent systems because of increased residual wax and poor brightness outcomes. Scouring technologies have been developed to remove wool wax without severely entangling fibres, but little attention has been given to the possibility of reducing wax content by genetic means to improve scouring efficiency. Wool wax was considered to protect fibres from light damage, but this assumption was challenged by Jackson (1973).

Increasing emphasis on the dual use of Merinos for meat and wool has increased the complexity of improving wool yield, particularly because dual-purpose animals are often held in dusty environments. Greeff et al. (2005) reported a negative genetic correlation between carcass fat depth and wool yield. Consequently, breeding programs designed to change wool yield should take into account the effects of alterations in fat depth on fitness and carcass quality.

Phenotypic associations

Phenotypic relationships are measured within a group of sheep and reflect the effects of both genetics and the environment, including that of feed supply. They can be used to indicate likely responsiveness to feeding regimes within a flock.

Ewes with high clean fleece weights wean fewer lambs

Within a flock, high CFW ewes tend to wean fewer lambs than low CFW ewes of the same liveweight. It unclear whether this effect can be overcome by improved nutrition. Hatcher and Refshauge (2005) conducted a retrospective study of the reproductive performance of ewes of the medium-wool strains of the NSW DPI's QPLU$ project, which included data gathered over more than 10 years. Ewes were classified into eight phenotypic groups. There were no significant phenotypic relationships between CFW and conception, proportion of ewes that lambed, litter size or the number of lambs born or marked. The only significant effect of CFW was on the number of lambs weaned: high CFW ewes weaned about four lambs per 100 ewes less than low CFW ewes ($P < 0.05$). Analyses of these data are continuing, and interactions between CFW and liveweight are currently being incorporated into the models.

A Sheep CRC study currently underway at the CSIRO research station at Bakers Hill, Western Australia, is examining two groups of 60 ewe hoggets each that were selected for high or low CFW from a cohort of 315 replacement ewe hoggets. The low CFW group differed from the high CFW group in mean CFW (2.5 kg vs. 3.6 kg, respectively; $P < 0.001$), with smaller differences in liveweight (50.1 kg vs. 51.8 kg, respectively; $P < 0.05$) and fibre diameter (17.6 µm vs. 18.1 µm, respectively; $P < 0.05$). Both groups had similar numbers of twins at scanning (21% vs. 25% for the low CFW and high CFW groups, respectively), but among the single-bearing ewes, low CFW ewes weaned more lambs than high CFW ewes (79% vs. 57%, $P < 0.05$).

Within flocks, sheep with high CFW have low plasma insulin concentrations (Adams et al., 2004). A similar trend was observed in the NSW DPI flocks, but an interaction between fleece weight and liveweight was also observed. Sheep with low CFW exhibited the expected negative correlation between plasma insulin concentration and depth of eye muscle ($P < 0.05$), but this relationship was absent in high CFW sheep. Adams et al. (2004) presented evidence that whole-body protein turnover increased as CFW increased; the NSW DPI results suggest that this may be caused in part by a loss of sensitivity of muscle deposition to insulin in sheep with high CFW.

Ewes that differ in fibre diameter do not differ in fitness

Analyses by conducted by the NSW DPI to date indicate that fibre diameter is phenotypically independent of wool production, body composition, growth and feed intake traits (Hatcher and Refshauge, 2005). Similarly, the large-scale QPLU$ reproduction analyses detected no significant relationships between fibre diameter and any of the components of reproduction. Liveweight was the principal driver of differences in all components of the reproduction rates of these ewes.

Phenotypic associations with yield vary with year

Studies conducted by the NSW DPI found that although CFW was significantly related to yield, the magnitude of the difference in yield between high and low CFW sheep varied between years. Neither fibre diameter nor liveweight had a significant impact on yield. Wool of phenotypically high CFW sheep had more wax ($P < 0.05$) and less suint ($P < 0.001$) and dust ($P < 0.05$) than that of low CFW sheep. Neither fibre diameter nor liveweight had a significant impact on any of the non-wool components of the fleece. However, it should be noted that the year effect was much greater than that attributed to CFW in the analysis. Estimates of phenotypic correlations between CFW, fibre diameter, liveweight and yield derived from the Condobolin Fine Wool Project (Hatcher, unpublished data) support these findings. The phenotypic correlation between CFW and yield was 0.43 ± 0.01; there was no significant phenotypic relationship between yield and fibre diameter (–0.05 ± 0.02) or liveweight (–0.03 ± 0.02).

Conclusions

The detailed biological studies discussed here explain why some woolgrowers are concerned about selection for high wool productivity. The results indicate that breeding objectives for wool should also take into account the effects of selection indices on fitness characteristics such as reproduction and resilience to poor nutrition. Our current knowledge of extreme wool production is as follows:

- Genetic selection for high CFW can result in a reduction of energy reserves relative to liveweight. This is likely to impair reproduction and survival.
- We do not yet know the extent to which the effect of CFW on fitness depends on nutrition. However, it is likely that when feed supply is limited, a high EBV for CFW will reduce reproduction to a greater extent than a low EBV for CFW.
- The biology underlying low lamb turnoff from sheep with fine wool remains unexplained.
- Wax may protect against light damage and dust penetration, but the optimum levels of wax for fibre quality, body composition and processing are still unclear.

- The link between wool yield and carcass fat content warrants further research.
- Strategic nutritional management of high CFW ewes during the breeding cycle, particularly those with multiple lambs, is an option for ensuring that the genetic potential of high CFW sheep is realised under commercial conditions. Advances in electronic identification and automated drafting systems will make this option more achievable in the future.

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