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Effects of selection accuracy, risk and young ewe fertility on breeding program design

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ABSTRACT: Selecting breeding animals at younger ages reduces generation interval, but also increases risk for long term profit because selection is less accurate and for management decisions because there is more variation in early reproductive performance of ewes. This study simulated different flock age structures and young ewe fertility levels in Merino breeding programs and compared average genetic gain and variation in genetic gain. Genetic gain increased by 18% when ewe fertility at 1 year of age increased from 10% to 90%. Age structure mainly influenced the risk of a particular breeding program design, as measured by increased variation in outcomes. Early selection in one or both sexes increased risk due to low accuracy of selection. The recent advent of breeding values utilizing genomic information presents opportunities to increase selection accuracy at younger ages and reduce the risk associated with early selection.
Keywords: reproduction; stochastic simulation; breeding program design

Introduction

An important aspect of sheep breeding programs is the age at first mating of rams and ewes. Joining sheep in the first year (at 7 months) has the benefit of lowering the generation interval but the accuracy of selection may be reduced. Selection on BLUP breeding values optimizes selection across age classes (James (1987)) but only with respect to mean outcomes. Breeding from younger stock increases the variability in outcomes due to lower selection accuracy. With both higher and lower genetic gains possible this represents increased risk to the breeder. Moreover, ewes joined at 7 months have lower fertility and more variable fertility than older animals (Fogarty *et al.* (2007)). Low fertility results in fewer candidates for selection thereby reducing selection intensity. Variable fertility levels from year to year from the joining of young ewes introduce more risk into the breeding program, through increased variability in potential outcomes. Thus, besides optimizing expected outcomes, breeders will also be interested in variability and risk associated with the available design options.

The aim of this study was to explore the impact of early selection of breeding stock on both mean and variation in genetic gain in sheep breeding programs, considering the effects of selection accuracy and young ewe fertility. This paper explores the balance between average genetic gain and risk, and how this depends on selection accuracy and reproductive rate.

Materials and Methods

Stochastic simulation was used to evaluate outcomes for a closed sheep breeding nucleus flock. We varied a number of parameters, including: age at first lamb for both rams and ewes (1 or 2 years of age) and flock fertility levels for young ewes. The model was described by Swan and Brown (2013). Rams and ewes were mated for up to 8 years. Culling each year was based on truncation selection across age classes based on estimated genetic merit. The initial round of selection either occurred early at 7 months of age or as traditionally, at 18 months of age depending on what ages animals had first progeny. Fertility of ewes was kept constant at 60% for 2 year olds, 80% for 3 year olds and 90% for animals over 4 years. Breeding program scenarios where ewes first had progeny at 1 year of age were run with 3 fertility levels: low fertility, 10%, moderate fertility, 50% and high fertility, 90%. Moderate fertility of 50% represents the current industry average for ewe fertility at 1 year of age (Bunter and Brown (2013)). The high and low fertility levels chosen do not necessarily represent industry figures, but were chosen to illustrate the range of possible results. Average litter sizes at birth for each age class of ewes were 1.0, 1.0, 1.1 and 1.2 for 1 year old, 2 year old, 3 year old and ewes over 4 years old respectively. The litter size of a ewe in a given age class was determined as described by Amer et al (1999).

Selection was based on ranking on the Merino Dual Purpose Index (DP3.5) which places most emphasis on increasing fleece weight, body weight, and reproduction rate whilst maintaining fiber diameter. All measurements were recorded when animals were 1 or 2 years of age with the exception of reproduction which was recorded throughout the ewe's lifetime. Genetic correlations and covariances for the simulation were taken from MERINOSELECT (Brown et al. (2007)). True breeding values were simulated as the sum of mid-parent breeding values plus a Mendelian segregation term which accounted for inbreeding. Phenotypes, estimated breeding values and index values were simulated as outlined by Swan and Brown (2013). In total 8 different breeding program scenarios for a flock of 300 Merino ewes mated annually to 10 rams were simulated. Initially 15 years of random selection was carried out followed by 10 years of selection based on estimated index values. 100 replicates of each scenario were run, generating improvement in overall index merit of the flock after 10 years of selection. The mean results and standard deviations of genetic gain in index units from the 100 replicates are reported.

Results and Discussion

As fertility of the yearling ewes increased, genetic gain also increased, in scenarios where ewes were selected early and rams traditionally. At low fertility (10%) average genetic gain was 64.6 ± 14.3 index units whilst at high fertility (90%) average genetic gain was 76.3 ± 14.7 index units after 10 years of selection (Table 1). This is not surprising as at higher fertility levels there are more progeny from which to select replacement rams and ewes, thus selection intensity increases and an 18% increase in expected genetic gain was seen.

Table 1. Expected genetic gain in index units after 10 years of index based selection. Rams and ewes had first progeny at either 1 or 2 years of age, representing early selection and traditional selection. Where ewes had first progeny at 1 year of age, 3 fertility levels were simulated, low (10%), medium (50%), high (90%). Standard deviation in brackets.

Age at first lamb		Ewe fertility at 1 year	Overall gain ($$ index units)
Rams	Ewes		
2	2	na	67.9 (12.6)
1	2	na	65.9 (14.4)
2	1	Low	64.6 (14.3)
2	1	Medium	69.0 (18.8)
2	1	High	76.3 (14.7)
1	1	Low	66.7 (14.4)
1	1	Medium	65.7 (18.5)
1	1	High	65.1 (20.1)

Young ewe fertility had the largest impact on mean genetic gain over 10 years of selection with only small differences in mean genetic gain seen for the different age structures compared in this study. Traditional selection on both sexes for first lambing at 2 years of age resulted in mean genetic gain of 67.9 ± 12.6 index units whilst early selection in males and traditional selection in females was marginally lower at 65.9 ± 14.4 index units (Table 1). Mean genetic gain when both sexes were selected early ranged from 65.1 to 66.7 index units with standard deviations ranging from 14.4 to 20.1 index units, perhaps the high selection intensity on the male side magnifies the effects of inaccurate selection on the next generation.

Age structure had a small impact on mean genetic gain but a larger impact on variation in response to selection, in the scenarios studied here. Under scenarios where rams or ewes or both were selected early the standard deviation of genetic gain was higher, ranging from 14.3 to 20.1 index units, than when rams and ewes were selected traditionally, 12.6 index units (Table 1). This is a result of wider variation in the genetic gain outcomes between replicates of the same scenario. Where early selection occurs, rams and ewes are selected as replacements at 7 months of age. This is before they have any phenotypic information recorded. Thus their breeding values have low accuracy as they are based only on mid-parent average and this leads to inaccurate selection of replacements and wider variation in results. Whilst wider variation in results indicates an opportunity for additional genetic gain from early selection, the inverse is also true and lower genetic gain may be realized. Thus, the mating of younger animals increases the risk of a breeding program. Here the degree of risk can be measured by the standard deviation of genetic gain, so scenarios with higher standard deviations also represent higher risk systems.

When comparing the tradeoff between average genetic gain and risk, the best solution from this study is early selection of females coupled with traditional selection in males if young ewe fertility is high as it offers high potential genetic gain with moderate standard deviation, 76.3 ± 14.7 index units, in comparison to traditional selection. In practice this may not be the case. It is well documented that young ewe fertility is highly variable not just between breeds and flocks but from season to season (Fogarty et al. (2007)). This wide variation in young ewe fertility between seasons introduces additional risk into the breeding program on top of that driven by inaccurate selection of replacement animals. Feedback from Australian Merino sheep breeders with experience in joining ewes at 7 months is that this large seasonal variation in young ewe fertility is an important consideration when deciding on the age to first mate young ewes.

The trend of increasing ewe fertility associated with increasing genetic gain was not seen when both rams and ewes were selected early. Inaccurate selection of replacement ewes has a smaller impact on flock genetic progress than inaccurate selection of replacement rams for two reasons. Firstly, as more ewes are retained each year there is a higher probability of retaining genetically superior animals. Secondly, under natural mating ewes have fewer progeny than rams so an individual ewe has a lower genetic contribution to the next generation than an individual ram. Inaccurate selection of rams is magnified in the next generation due to the relatively larger impact that an individual ram's genes have on the next generation.

Under scenarios where early selection occurs, selection candidates only have information based on mid parent average. Thus, the amount of information available on the parents of selection candidates will also influence selection accuracy. Where early selection occurs on both sexes, some of the parents of the selection candidates will be less than 2 years old when their progeny are chosen as replacements. The parents themselves will not have phenotypic information for adult traits used in the selection index, so their breeding values will have a lower accuracy than that of older parents. In particular, young sires will not have any reproductive information to be used in calculation of progeny breeding values as it is a sex-limited trait. As reproduction rate is one of the three key traits in the DP3.5 index, progeny from young sires will have lower accuracy breeding values at selection. This perhaps explains why when both parents are selected early we do not see a clear impact of increased fertility on mean genetic progress and see the highest standard deviation (20.1 index units) for this scenario.

The early selection scenarios modelled here may be an approximation of early selection in the Australian sheep industry, in particular with young rams. Most studs practicing early selection in rams have a two stage selection process where promising young sires will be used in their first year but additional young rams are retained and not bred in the first year. At 18 months of age, when the breeding value accuracy of these rams has improved, all rams including those previously used are re-assessed for their potential merit as sires. Further work aims to consider this two-stage selection process in rams.

Risk-averse breeding program designs have previously not utilized early selection due to lower accuracy breeding values. This is particularly relevant for Merinos where key economic traits such as reproductive rate are measured later in life and early selection requires accurate breeding values at 7 months of age. The recent advent of genomic breeding values in the Australian Sheep Industry offers the opportunity to increase the accuracy of breeding values on young animals, reducing this risk. In the case of reproductive traits preliminary work shows that incorporation of genomic information increases the accuracy of prediction compared to BLUP alone (Daetwyler et al. (2013)). Although these results are promising, at this stage genomic predictions are not available for reproduction traits which have high importance in Merino indexes. Provided adequate accuracies for genomic breeding values for reproduction can be achieved, replacements will be able to be selected with greater confidence and the risk of breeding programs adopting early selection will be reduced. Given the large impact that young ewe fertility has on expected genetic gain, work to improve the reliability of young ewe reproductive performance will reduce the risk introduced by this factor. This would increase the attractiveness of early selection of ewes. Development of post-weaning breeding values for key fleece traits may also assist in improving selection accuracy at 7 months, providing these new traits are correlated with adult characteristics.

Conclusion

Improvement of young ewe fertility had the largest impact on expected genetic gain when comparing scenarios studied to traditional selection. However, early selection introduces more risk into the breeding program as outcomes are more variable due to lower selection accuracy and variation in young ewe fertility. Genomic breeding values offer the opportunity to improve selection accuracy at younger ages, although currently these are not available for reproductive traits. Improving the reliability of young ewe fertility will further reduce the risk of breeding program design incorporating young ewes. When considering the appropriate breeding program design for a Merino enterprise, numerous factors must be considered including balancing generation interval, selection accuracy, the impact of early fertility and the farmer's attitude to risk.

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