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Is eating less better? Relationship of feed efficiency with production traits in New Zealand sheep

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Introduction

Sustain Sheep is an international collaboration involving Ireland (TEAGASC, ICBF), the UK (SRUC), New Zealand (NZ) (Bioeconomy Science Institute–AgResearch), France (INRAE), Norway (NSG, NMBU) and Uruguay (INIA), with the objective of assessing the impact of reducing global sheep methane emissions. The project aims to understand how selecting for residual feed intake in young female sheep affects methane emissions and lifetime productivity. Residual feed intake (RFI) is a measure of feed efficiency, indicating whether an animal is consuming more or less energy for its biological outcomes than predicted (Johnson *et al*., 2016). The trait of RFI is moderately heritable in NZ sheep (Johnson *et al*., 2022). It is an important trait as feed represents the greatest production cost and significantly impacts environmental sustainability (Ferreira *et al*., 2024). Traditionally measured in growing males, this study measured RFI in growing females, ranked them, and tracked these animals through multiple lambing's to assess impacts on lifetime production traits and breeding objectives.

In New Zealand, genetic improvement in sheep is primarily achieved through the use of breeding values (BVs) (Newman *et al*., 2000), which estimate an animal's genetic merit for specific traits relative to the population mean. Breeding Values are routinely calculated for production traits and are combined into selection indices for various breeding objectives (Anon, 2022). Knowledge of the relationship between RFI and existing traits and selection indices is critical for integrating feed efficiency into current breeding programs without compromising progress in other economically important traits. This paper contributes to this knowledge by investigating the correlation between the RFI BVs and BVs for individual traits and selection indexes, together with comparing the BVs for animals selected for extreme (high and low) RFI BVs.

Materials & Methods

This study analysed data from 1,549 ewe lambs from four New Zealand sheep flocks (Sheep Improvement Limited Flock Codes:2638, 3633, 4640 and 5010) born between 2014-2021 that had individual feed intake together with weight and growth traits measured through an indoor feed intake facility (Johnson *et al*., 2016). The resulting data was used to calculate RFI using the formula of Koch *et al*. (1963) and RFI breeding values (BV) calculated through ASREML (Butler *et al*., 2023). Associations between the RFI BV and 23 other industry-relevant BVs (SIL, 2022) were investigated using Pearson's correlation coefficients with significance determined at $p < 0.05$: Weaning weight (WWTBV), weaning weight maternal (WWTMBV), carcass weight (CWBV), adult body weight (EWTBV), fat yield of carcass (FATYBV), lean yield (LEANYBV), fleece weight as a lamb (LFWBV), fleece weight at 12 months (FW12BV), adult ewe fleece weight (EFWBV), lamb survival (SURBV), lamb survival maternal (SURMBV), number of lambs born (NLBBV), faecal egg count for adult ewes (AFECBV), faecal egg count in lambs occurring in late summer (FEC1BV), faecal egg count in lambs occurring in autumn (FEC2BV), live weight 8 months (LW8BV), shoulder lean yield (SHLYBV), hind-quarter lean yield (HQLYBV), loin lean yield (LNLYBV), lamb dag score (LDAGBV), adult dag score (ADAGBV), methane production (PACCH4BV) and carbon

dioxide production (PACCO2BV) (SIL, 2022). Associations between RFI BVs and selection indices for maternal worth traits (MW) and dual purpose traits (DP) were investigated using Pearson's correlation coefficients with significance determined at $p < 0.05$: NZ maternal worth (NZMW), DP lamb growth (DPG), DP meat (yield) (DPM), DP adult size (DPA), DP reproduction (DPR), DP lamb survival (DPS), DP internal parasite resistance (DPF), DP wool production (DPW), DP dag score (DPD), MW + Fec (MW+F), MW + meat (MW+M), MW + Dags (MW+D), DP capped reproduction (DPCR), MW + wool + meat + FEC + dags (Ma+W+M+F+D) (SIL, 2022). The top and bottom 10% of animals within each of the eleven flock-within-year measurement groups were selected based on their RFI BVs, and differences between these groups were assessed using two-sample Student's t-tests ($p < 0.05$) for the industry-relevant BVs and selection indexes, with Cohen's d effect sizes also calculated. The top 10% of RFI BVs are the least feed efficient animals and the bottom 10% of RFI BVs are the most efficient animals.

Results & Discussion

RFI BVs were significantly correlated with 12 of 23 industry-relevant BVs and 9 of 14 selection indices (Table 1). Correlation coefficients ranged from -0.127 to 0.092 for industry relevant BVs and -0.077 to 0.126 for selection indices. The RFI BV was significantly but weakly correlated with PACCH4BV (r=-0.093), indicating that selecting for reduced methane will result in the RFIBV increasing and less feed efficient animals being selected. However, as this relationship is weak, positive gain for both traits can be achieved using selection indices with appropriate economic weightings on both traits.

Table 1. Significant associations between RFI BV for 1,549 ewe lambs from four New Zealand sheep flocks (2638, 3633, 4640, 5010) born between 2014-2021 with 12 of the 23 other industry-relevant BVs investigated being significant, and 9 of the 14 selection indices from maternal worth and dual-purpose traits being significant. Significant P-value<0.05, 3dp.

Individual Trait BV	Correlation	P-value	Selection Index	Correlation	P-value
FEC1BV	-0.127	0.000	DPF	-0.126	0.000
AFECBV	-0.116	0.000	MW.F	0.095	0.000
FEC2BV	-0.106	0.000	DPR	0.092	0.000
LW8BV	-0.102	0.000	DPG	-0.077	0.003
PACCH4BV	-0.093	0.000	DPM	-0.064	0.011
NLBBV	0.092	0.000	DPW	0.064	0.011
WWTBV	-0.088	0.001	DPCR	0.063	0.013
CWBV	-0.088	0.001	DPA	0.061	0.016
EFWBV	0.070	0.006	Ma.W.M.F.D	0.061	0.017
FW12BV	0.067	0.009			
EWTBV	-0.061	0.016			
PACCO2BV	0.052	0.041			

The most significant differences between the animals selected for RFI BV extremes were for SHLYBV, PACCH4BV, LEANYBV, and HQLYBV, each with three of eleven groups statistically different (Figure 1). Effect sizes ranged from medium to very large: SHLYBV (Cohen's d=0.908 to 1.529), PACCH4BV (Cohen's d=-0.781 to -1.103), LEANYBV (Cohen's d=0.948 to 1.464), and HQLYBV (Cohen's d=-0.8 to 1.812). The direction of relationships varied by group, in some groups, more feed-efficient animals (lower RFIBV) had higher lean yield, while in others the relationship was reversed. In the three groups with significant differences for PACCH4BV, more feed-efficient animals (bottom 10% of RFIBV) had higher PACCH4BV, indicating they produced more methane than less feed efficient animals. This

pattern within specific flock-year groups reflects the same pattern seen within the combined all flock-year analysis. This relationship between RFI and methane has previously been observed in a subset (excluding Flock 5010) of these animals with a genetic correlation of -0.28 ± 0.16 (Johnson *et al*., 2022). The overall trend for the relationship between carcass composition and RFI being that the feed efficient animals (bottom 10% RFI BVs) were fatter. A genetic correlation between total body fat (estimated from computed tomography scanning) and RFI of -0.58 ± 0.18 was also reported in the Johnson *et al*. 2022 study. Ultimately, the goal of sustainable breeding programmes is to identify animals that maximise production outcomes from less feed, whilst reducing methane emissions. The relationship between RFI and other traits seen in this study whilst significant are weak indicating that with use of selection indices we can ensure simultaneous genetic improvement across all traits including both methane emissions and RFI.

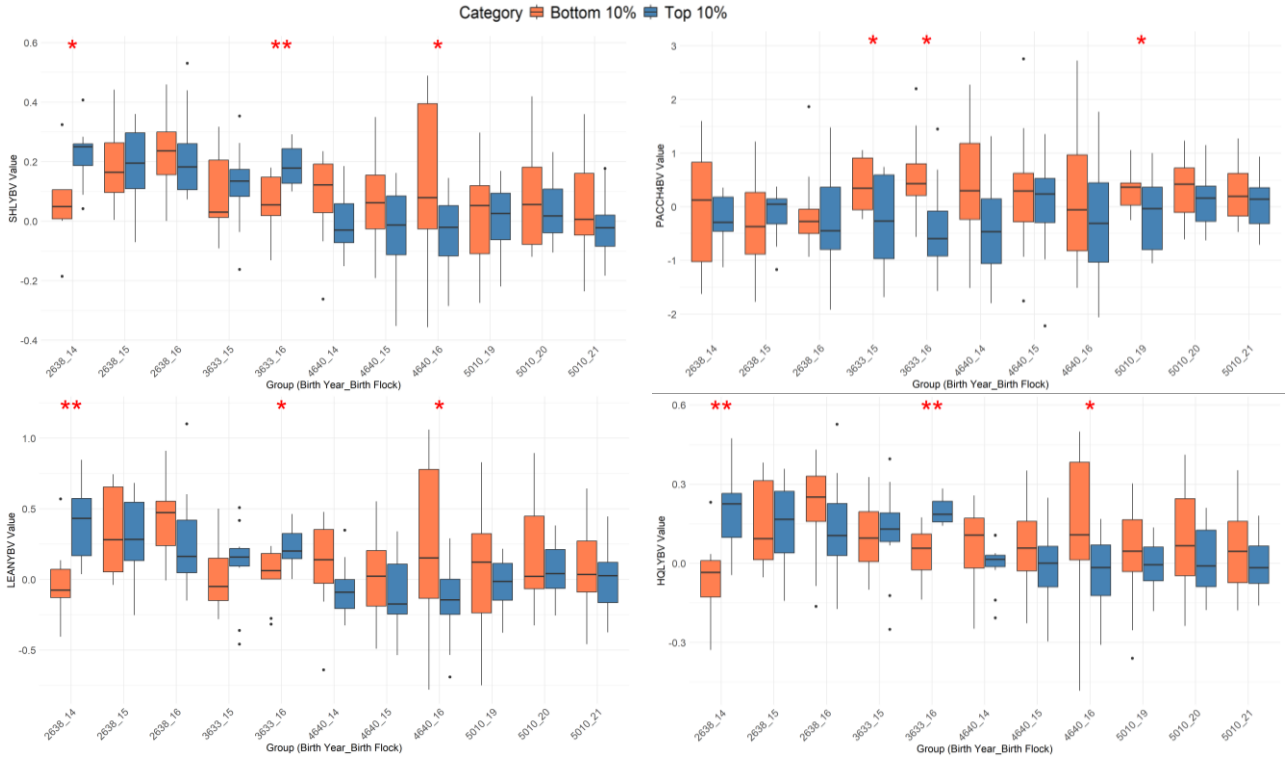

Figure 1. Differences for the for the top 10% (least efficient) and bottom 10% (most efficient) within eleven measurement groups (flock within year) RFI BV and 4 industry relevant BVs (SHLYBV, PACCH4BV, LEANYBV and HQLYBV). Box plots show median, quartiles, and range. Differences were tested using independent samples t-tests; * $p < 0.05$, ** $p < 0.01$.

We also compared the groups for the MW and DP selection indices. Four groups differed significantly for MW + meat with medium to very large effects (Cohen's d=-1.287 to 2.10). Three groups differed for MW + wool + meat + FEC + dags with medium to very large effects (Cohen's d=-0.779 to 2.427) and three groups differed significantly for DP meat (yield) index with large to very large effects (Cohen's d=-1.22 to -0.858) (Figure 2). These findings follow on from above in that differences were observed in indexes in which "meat" was included. Similarly to the BV traits the magnitude and direction of effects vary by flock and year. Increasing sample sizes beyond the current 13-14 animals per extreme group (from ~200 animals per flock-year) may help clarify whether all patterns seen in this analysis reflect true biological variation or sampling limitations.

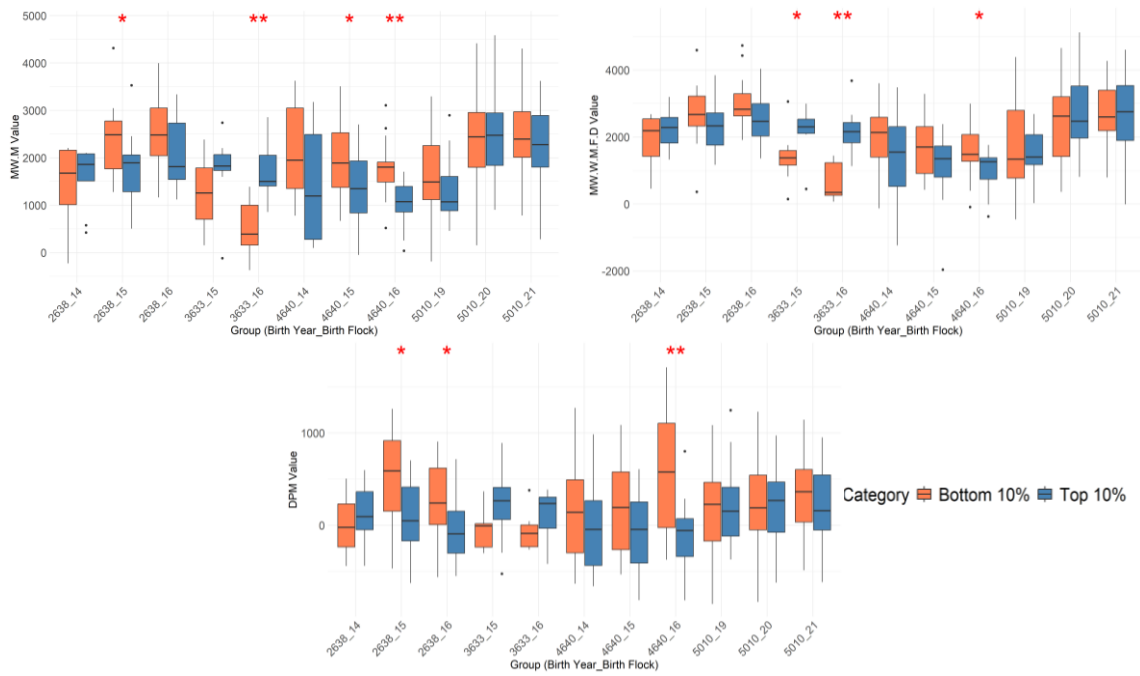

Figure 2. Differences between the top and bottom 10% (within eleven flock-year groups) are shown for RFI BV and three selection indices: MW + meat, MW + wool + meat + FEC + dags, and DP meat (yield). Independent-samples t-tests were used; * $p < 0.05$, ** $p < 0.01$.

Conclusions

Results indicate that relationships between RFI breeding values and other traits in New Zealand sheep are significant but generally weak, whether assessed through correlations or comparisons of extreme RFI groups. Variation in directional effects suggests larger sample sizes are needed for clearer interpretation. Whilst some relationships between the investigated traits were significant, they were overall weak and support that simultaneous selection can be achieved with selection indexes. Future work will quantify genetic correlations among RFI, methane, and lifetime production traits to inform development of multi-trait indices.

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