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GENETIC CORRELATIONS BETWEEN LAMB SURVIVAL, BIRTH WEIGHT, AND GESTATION LENGTH DIFFER BETWEEN BIRTH TYPES

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SUMMARY

Lamb survival significantly limits the productivity of the Australian sheep industry, with twin and multiple-born lambs suffering greater mortality rates than single-born lambs. Using data from the Sheep CRC Information Nucleus Flocks, correlation estimates for gestation length, birthweight, and lamb survival across different birth types were examined. Gestation length and lamb survival are uncorrelated genetically in both singles and twins (0.02 and 0.04) but have a low genetic correlation of 0.27 for multiple-born lambs. Birthweight was lowly and negatively genetically correlated to singles survival (-0.29), negligibly correlated for twins (-0.15), and lowly positively correlated for multiples (0.37). The results of this study demonstrate that the influence of birthweight on survival varies significantly across different litter sizes, and selecting for birthweight to improve lamb survival would not be beneficial for survival across all birth types.

INTRODUCTION

Lamb survival is a significant problem in Australia, severely limiting the productivity of the sheep flock (Hinch and Brien 2014). Phenotypically, birthweight is one of the largest influences on lamb survival within the first few days of life (Oldham *et al.* 2011). Litter size significantly impacts lamb survival, with twin survival rates reported at 27% below single-born survival (Kleemann and Walker 2005) and is associated with lower birthweights and slower growth rates (Dwyer and Morgan 2006). Gestation length is also known to be shorter for larger litters, leading to lower birthweights and lower lamb viability (Dwyer and Morgan 2006; Li and Brown 2015).

Lamb survival has a very low direct heritability, with estimates generally calculated around 0.01-0.03 and only marginally higher estimates for maternal heritability, averaging 0.05-0.06 (Safari *et al.* 2005; Brien *et al.* 2010), suggesting that direct selection to improve survival would be inefficient. Indirect selection to improve lamb survival may be more effective, however it is vital to account for any agonistic and antagonistic effects on survival as a consequence of correlations with other traits when indirect selection is practiced. The genetic parameters for birthweight are widely varied throughout literature, having anywhere between a low to moderate heritability and often with little to no genetic correlation with lamb survival despite the phenotypic curvilinear relationship (Brien *et al.* 2014). Despite reports of lamb survival and birthweight varying significantly depending on litter size, very few papers have examined this idea in detail (Li and Brown 2015). This paper reports on the analysis of the relationship of birthweight and lamb survival across different litter sizes and discusses whether they should be treated as separate traits depending on birth type.

MATERIALS AND METHODS

Information Nucleus Flock. The data used was from the Sheep CRC Information Nucleus Flock (INF), a collection of records from 2007-2011 over eight locations across Australia with Merino and crossbred ewes that were inseminated to Merino, maternal and terminal breed rams. Further details on design, data collection and management of the INF have been reported by Fogarty *et al.* (2007) and Geenty *et al.* (2014). Gestation length (GL) was treated as a trait of the lamb and calculated from AI dates (conception) and lamb birth dates, with records above 160 days and below 138 days removed due to biological improbability. Lamb survival to three days (S3) was chosen as the primary focus as it accounts for 66% of lamb mortalities to weaning. Birthweight (BWT) was also analysed.

Statistical Analysis. The statistical package ASReml (Gilmour 2015) was used to estimate genetic and phenotypic variance and covariance components, heritability, and correlations between GL, BWT, and S3 by fitting a linear mixed model with restricted maximum likelihood. An animal model was initially attempted, however, due to a lack of convergence, this was unable to test the hypotheses herein and so a sire model was used throughout the study. The dam permanent environmental effect was also removed from the model due to lack of depth within the pedigree.

Model 1. Three univariate analyses were run to estimate variance components for GL, S3 and BWT. Analyses included the fixed effects of type of birth (TOB; singles, twins, multiples=3+), age of dam (AOD; 2-8+), sex (male (M) or female (F)), location (8 sites), genetic groups (dam breed, sire breed) and year (2007-2011), significant two-way interactions (AOD by year, flock by year, flock by year by TOB) and the random terms of sire and dam. The sire variance includes ¼ additive genetic whereas dam includes ¼ additive genetic variance plus maternal genetic and environmental effects. A trivariate analyses was performed to estimate genetic correlations between GL, S3 and BWT.

Model 2. Separate univariate models for singles, twins and multiples were fitted to estimate separate sire and dam variance components for each TOB (singles, twins and multiples) for the three traits, GL, S3 and BWT. The fixed effects and random terms were as outlined in Model 1. Multiple records per litter were randomly removed for gestation and treated as missing as they all had the same gestation length, as per the technique used by Li and Brown (2015), leaving a total of 15,097 gestation length records. A series of bivariate analyses were performed using Model 2 fixed and random effects to estimate the genetic and phenotypic correlation between GL, LS3 and BWT.

RESULTS

Basic statistics and heritability estimates were calculated for the overall traits as outline in Model 1 and for the separated traits as outlined in Model 2 (Table 1). Separating the traits by TOB (Model 2) was a significant improvement over Model 1 (Table 1).

Table 1: Summary statistics and heritability estimates for gestation length (GL), birthweight (BWT) and lamb survival to three days (S3) for the overall trait (Model 1) and separated by type of birth (Model 2) with the Likelihood Ratio Test (LRT) statistic comparing Model 1 to Model 2 (* = significant at the 0.001 level - 32.91 at 12 degrees of freedom)

		Mean	σ	Count	h^2	LTR
GL		149.4 days	2.6 days	15 097	0.53 ± 0.05	
	Single	149.8 days	2.6 days	7 267	0.53 ± 0.05	79.38*
	Twin	149.1 days	2.5 days	6 762	0.54 ± 0.15	
	Multiple	148.6 days	2.5 days	1 068	0.54 ± 0.15	
BWT		4.8 kg	1.1 kg	23 619	0.16 ± 0.02	
	Single	5.5 kg	1.1 kg	7 267	0.21 ± 0.03	386.82*
	Twin	4.6 kg	1.0 kg	13 229	0.12 ± 0.02	
	Multiple	3.8 kg	0.9 kg	3 123	0.16 ± 0.07	
S3		0.88	0.32	23 619	0.02 ± 0.01	
	Single	0.94	0.25	7 267	0.01 ± 0.02	320.88*
	Twin	0.89	0.32	13 229	0.04 ± 0.01	
	Multiple	0.72	0.45	3 123	0.15 ± 0.06	

An initial analysis was performed to calculate the correlation between GL, BWT, and S3 as singular traits in a univariate model (Model 1; Table 2) before the traits were considered separate by TOB (Model 2). Phenotypic correlations were not calculated between overall traits because the model was improved by separating the traits and it was deemed unnecessary.

The between trait genetic correlations for BWT and S3 had an increasing trend, being lowly negative for single lambs, negligibly negative for twins, and lowly positive for multiples (Table 2). The correlation between GL and S3 were negligible for single and twin lambs while there was a low correlation for multiples (0.27), though with a large standard error. The phenotypic correlation between S3 and BWT was greater for larger litters (Table 2), with the phenotypic correlation between GL and S3 being negligible for all litter sizes.

Table 2: Genetic sire correlations between gestation length (GL), birthweight (BWT) and lamb survival to three days (S3) by type of birth (with standard errors)

	Genetic			Phenotypic		
	GL-S3	GL-BWT	BWT-S3	GL-S3	GL-BWT	BWT-S3
Overall	-0.01 (0.11)	0.36 (0.06)	-0.31 (0.13)			
Singles	0.07 (0.30)	0.31 (0.08)	-0.29 (0.42)	-0.02 (0.01)	0.34 (0.01)	0.07 (0.01)
Twins	-0.03 (0.13)	0.41 (0.08)	-0.15 (0.17)	0.04 (0.01)	0.33 (0.01)	0.18 (0.01)
Multiples	0.27 (0.24)	0.53 (0.22)	0.37 (0.29)	0.04 (0.03)	0.29 (0.03)	0.28 (0.02)

DISCUSSION

Birthweight has a complex relationship with lamb survival, as described in literature. The two traits are known to be phenotypically linked, with some reports referring to birthweight as one of the biggest factors influencing the initial survival of the lamb, with the relationship of a negative quadratic nature (Hatcher *et al.* 2009; Celi and Bush 2010; Oldham *et al.* 2011). Hatcher *et al.* (2009) have described the optimum phenotypic birthweight for lamb survival as being different between singles, twins, and multiples, with attempts to select for higher birthweight to improve twin and multiple-born lamb survival potentially resulting in a decrease in single-born lamb survival rates due to dystocia. Considering this, an expected trend was seen in the genetic correlation (Table 2) between birthweight and lamb survival where single and twin-born lambs were lowly negatively correlated, -0.29 and -0.15 respectively, while multiple-born lambs were lowly positively correlated (0.37). The overall genetic relationship between birthweight and survival was lowly negative (-0.31, Table 2) and within the range reported in previous literature (Brien *et al.* 2014); segregation by type of birth gave a clearer indication that lamb survival is a genetically separate trait across birth types (Table 1; Kelly *et al.* 2016). Female pigs, which consistently have large litter sizes, similarly demonstrate a low positive genetic correlation between survival and birthweight (Tabuaciri *et al.* 2010). Phenotypically, the correlation between birthweight and survival increases as litter size increased (Table 3), indicating that birthweight had a more significant influence on survival in larger litter sizes and is likely due to the smaller size of lambs born as multiples. Despite following an expected trend, survival and birthweight were not as highly correlated as expected. Although the likelihood ratio test (Table 1) provides evidence that separating by birth type improves the statistical model, the precision of these correlations are low. Given the low heritability and variation, combined with the lack of precision in correlations estimates, suggests birthweight is unlikely to be a suitable indicator trait for lamb survival.

The genetic correlations between gestation length and birthweight (Table 2) for twins and multiple-born lambs follow the expected trend of consistently moderately positive, as reported in piglets (Rydhmer *et al.* 2008). This aligns with the overall genetic correlation of 0.36 between gestation length and birthweight (Table 2). This suggests that longer gestation length may improve the birthweight of multiple-born lambs and potentially improve their survival, but would also increase birthweight of single and twin lambs and this could be detrimental to their survival. The direct correlation between survival and gestation length for single and twin-born lambs was negligible (Table 2), which differs from earlier results from Li and Brown (2015), who reported low positive correlations between gestation length and lamb survival for single and twin-born lambs.

Birthweight is critical to early lamb survival and is associated with many genetic factors, such as litter size. With the economic push to increase litter size in sheep (Swan 2009), it's vital to understand the interaction between litter size, birthweight, and survival. The results of this study demonstrate that genetically selecting for birthweight to improve lamb survival does not appear to be beneficial for survival across different litter sizes. Despite interesting correlations seen in separating birthweight and lamb survival by birth type and that this is an improvement on the single-trait model (Table 1), these correlations and their precisions are low (Table 2). Furthermore, treating the traits as separate by birth type would be difficult to implement in a practical breeding plan, although economic value for birthweight may change with mean litter size.

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