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Genetic Evaluation of Weaning Weight and the Probability of Lambing at 1 Year of Age in Targhee Lambs

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Summary

The objective of this study was to investigate genetic control of 120-d weaning weight and the probability of lambing at 1 yr of age in Targhee ewe lambs. Records of 5,967 ewe lambs born from 1989 to 2012 and first exposed to rams for breeding at approximately 7 mo of age were analyzed. Records included lamb birth dates, sire, dam, type of birth and rearing, dam age, and weaning weight and, for ewe lambs, the breeding pen and subsequent lambing data. Weaning weight was evaluated as a continuous variable, and lambing data were recorded as a binomial trait, but both traits were analyzed as continuous variables. Full-term lambs (either born alive or stillborn) were recorded as a lambing success (i.e., 1); failure to produce a full-term lamb was indicated with a 0. The relationship matrix included 14,041 animals and at least four generations of pedigree information, with more generations included for animals born in later years of the study. Heritability estimates were 0.14 ± 0.02 for 120-d weaning weight and 0.15 ± 0.04 for probability of lambing. Phenotypic and genetic correlations between the two traits were 0.18 ± 0.02 and -0.23 ± 0.18, respectively. Weaning weight and the probability of lambing at 1 yr of age are thus expected to respond to selection. Ewe lambs with heavier weaning weights were more likely to lamb at 1 yr of age, but this is an environmental, rather than genetic relationship, and selection for ability to lamb at 1 yr of age may result in a small decrease in genetic merit for weaning weight.

Key Words: Sheep, Genetics, Growth, Reproduction, Weaning

Introduction

Dickerson (1970) stated that costs of livestock products depend on the efficiency of reproduction, female production, and growth of offspring and concluded that the major opportunity to improve efficiency in sheep production is to increase rate of reproduction. One method to improve reproductive efficiency is to increase the probability that ewes will lamb at 1 yr of age. Breeding ewes to lamb at 1 yr of age has been proposed for several decades (Briggs, 1936; Hume, 1939; Spencer et al., 1942; Cannon and Bath, 1969; Southam et al., 1971) as a means to increase lifetime productivity (Dyrmundsson, 1973, 1981; Levine et al., 1978; Fogarty et al., 2007), but with the caveat that ewe lambs must be properly developed before breeding (Hume, 1939; Spencer et al., 1942). Lifetime-lamb production is greater for ewes that lamb as yearlings than for ewes that lamb for the first time at 2 yr of age (Bowstead, 1930; Spencer et al., 1942; Hulet et al., 1969; Baker et al., 1978; Levine et al., 1978; Fogarty et al., 2007).

When compared with ewes that did not lamb at 1 yr of age, body weights of ewes that lambed at 1 yr of age were less at lambing (Cannon and Bath, 1969), at the end of the first lactation (Griswold, 1932), and at 18 mo of age (Spencer et al., 1942). Body weights did not differ at maturity. Lambing at 1 yr of age does not seem to adversely affect the ewes or their lambs (Fogarty et al., 2007). However, compared to ewes that lamb at 1 yr of age, ewes that lamb for the first time at 2 yr of age require an additional 12 mo of inputs without commensurate output, and overall production efficiency (i.e., ratio of useful output to total input) is expected to be less. Thus, a study was initiated at the USDA, ARS, U.S. Sheep Experiment Station (USSES) to determine the additive genetic control of the probability of lambing at 1 yr of age in Targhee ewes and estimate genetic and phenotypic relationships between the probability of lambing and lamb-weaning weight.

Materials and Methods

The USSES Institutional Animal Care and Use Committee reviewed and approved the husbandry practices and experimental procedures used in this study.

Animals

Lambing performance at 1 yr of age was analyzed using records of 5,967 Targhee ewe lambs born from 1989 to 2012 at USSES. Ewes lambed from mid-March through early May. Ewes and lambs were herded on sagebrush steppe range beginning in late April or early May and subalpine range beginning in early July. Selection and management of ewe lambs, after weaning and during breeding, varied across years, as experimental priorities shifted over time (Table 1). Before 2010, ewe lambs were weaned in late August, placed in feedlot pens for breeding, and managed in a feedlot until lambing. Beginning in 2010, ewe lambs were weaned in early September and managed in a feedlot until lambing. Before 2010, ewe lambs were penned with service sires for breeding for 55 d. Beginning in 2010, the breeding period was reduced to 34 d. The average age at weaning was 113 d, and the average age at the start of breeding was approximately 200 d. Ewe lambs were occasionally mated in multi-sire pens (Table 1), producing either purebred or crossbred lambs. Lambs resulting from these matings were not retained in the USSES purebred Targhee flock. In 1998 and 2002, mixtures of single-sire and multi-sire pens were used. From 2007 to 2011, ewe lambs were hand-mated to rams in an experiment to study the attainment of puberty in ewe lambs. Protocols for this puberty study dictated that ewe lambs were randomly assigned to service sires at each mating opportunity, so ewe lambs could have been mated to more than one ram during the breeding season, precluding identification of a specific service sire for the entire breeding season. Because of this constraint, the service sire of the ewe lambs was set equal to the breeding-pen number. As a result, differences in probability of lambing associated with service-sire effects in these years represented a general effect of the breeding pen.

Measurements

The data record for each lamb born included the birth date, sire, dam, type of birth and rearing, dam age, and weaning weight. Records for ewe lambs that were exposed to rams also included the breeding pen and subsequent lambing data. The type of birth and rearing variable grouped lambs according to number born and number reared and had seven classes (1-1, 1-2, 2-1, 2-2, 3-1, 3-2, and 3-3). A small number of lambs (0.004 percent of the data) born in litters of size four were removed from the data. The record of lambing success for a yearling ewe was a binomial trait (i.e., 1 or 0). Yearling ewes that delivered live or stillborn, but apparently full-term, lambs within approximately 10 d of their expected lambing date received a lambing success code of 1; yearling ewes that did not meet this criterion received a code of 0. We did not differentiate between ewe lambs that did not conceive and those that conceived, but did not deliver a full-term lamb. Ewe lambs in the fertility data set had 324 sires and 1,753 dams.

Weaning weights of ram (n = 4,503), wether (n = 1,338), and ewe lambs (n = 5,935) born in 1989 through 2012 and therefore contemporary with the ewe lambs in the yearling ewe fertility data set and their progeny were also extracted from USSES data sets. Based mainly on the productivity of their dams and associated low likelihood that they would be retained as breeding rams, an average of 23 percent of male lambs were selected before lambing to be castrated. However, the proportion of males that were castrated varied widely across years, from less than 1 percent to 51 percent. The final additive genetic relationship matrix for all lambs with weaning weights or yearling-ewe-lambing records contained 14,041 animals.

Statistical Methods

The ASREML software package (VSN International; Hemel Hempstead, U.K.) was used to estimate genetic parameters, and chi-squared tests ($P < 0.05$) of log-likelihood values were used to arrive at the final model. A univariate analysis of probability of lambing at 1 yr of age (Kirschten et al., 2013) using this dataset was previously completed using a binomial model. However, the bivariate model used to jointly analyze effects of probability of lambing and lamb-weaning weight in the current study did not

Table 1. Distribution of yearling lambing data among years.

Year born	No. of ewe lambs: Weaned	No. of ewe lambs: Exposed to rams	Weaning weight mean and SD (kg) for ewe lambs: Weaned	Weaning weight mean and SD (kg) for ewe lambs: Exposed to rams	Probability of lambing[a]	Single-sire mated?
1989	259	166	33.7 ± 5.9	36.7 ± 4.3	0.74	No
1990	311	170	32.2 ± 5.7	35.9 ± 3.7	0.61	No
1991	302	164	32.9 ± 5.4	35.6 ± 4.4	0.43	Yes
1992	442	197	29.8 ± 5.5	33.2 ± 4.3	0.31	No
1993	232	108	28.1 ± 6.1	28.1 ± 5.7	0.42	Yes
1994	193	90	30.1 ± 5.9	32.8 ± 4.2	0.38	Yes
1995	199	83	32.5 ± 5.4	33.8 ± 4.6	0.63	No
1996	273	124	32.2 ± 5.0	35.0 ± 3.7	0.79	No
1997	250	122	29.8 ± 5.1	32.2 ± 3.7	0.53	Yes
1998	240	144	32.8 ± 5.2	33.8 ± 5.1	0.71	Mix[b]
1999	275	142	32.8 ± 5.5	34.5 ± 4.5	0.46	Yes
2000	251	135	31.4 ± 6.6	33.9 ± 5.8	0.41	Yes
2001	202	129	34.3 ± 5.3	35.8 ± 5.2	0.40	Yes
2002	288	118	34.2 ± 5.7	38.9 ± 3.7	0.26	Mix[b]
2003	140	67	36.9 ± 4.9	39.7 ± 3.4	0.36	Yes
2004	183	118	36.1 ± 5.2	38.7 ± 4.0	0.69	Yes
2005	217	159	38.3 ± 5.7	40.2 ± 4.7	0.46	Yes
2006	201	163	34.2 ± 4.9	35.3 ± 4.3	0.56	Yes
2007	206	174	30.5 ± 5.7	30.7 ± 4.4	0.53	No
2008	204	177	35.6 ± 6.3	35.7 ± 5.8	0.34	No
2009	188	183	38.2 ± 5.9	38.3 ± 5.9	0.54	Yes
2010	239	135	35.4 ± 6.1	37.1 ± 5.8	0.34	No
2011	185	33	31.3 ± 6.3	37.5 ± 5.0	0.49	No
2012	238	185	31.4 ± 6.1	33.3 ± 5.3	0.49	Yes

[a] Number lambed / number mated
[b] Mixtures of single-sire and multi-sire pens.

converge when the probability of lambing was modeled as a binomial trait. A continuous normal distribution was therefore assumed for both traits to allow estimation of genetic parameters in the bivariate model. The final model for both traits in the current study included fixed effects of birth year, dam age, and type of birth and rearing and a random-animal, additive-genetic effect. The final model for weaning weight also included maternal-additive and permanent-environment effects (both fitted as random) and a continuous-linear effect of weaning age. The final model for probability of lambing at 1 yr of age also included a random effect of breeding pen and a continuous-linear effect of birth date of the ewe lamb.

Results and Discussion

Preliminary analyses of 120-d weaning weights revealed significant heterogeneity of variance among sexes (Table 2). Ram lambs were heavier than both ewe and wether lambs, and, based on F ratios of residual variances, also more variable ($P < 0.001$ and $P = 0.02$, respectively). However, CV differed among sexes by at most 1.1 percent. Lamb weaning weights were therefore standardized to a ewe-lamb basis before estimation of genetic parameters by multiplying weaning weights of ram and wether lambs by 0.923 and 0.977, respectively. By contrast, yearly means for weaning weights of unselected ewe lambs (Table 1) exhibited only a small negative correlation (r) with SD (r = -0.15; $P > 0.40$), and therefore uniformity of variation in weaning weight among years was assumed. A more substantial negative correlation was observed between annual means and CV (r = -0.75; $P < 0.001$). Favorable environmental conditions that increased the mean-weaning weight were thus not associated with greater absolute variation among animals and reduced variation relative to the mean.

The heritability estimate for weaning weight was 0.14 ± 0.02, the maternal heritability was 0.11 ± 0.02, and the permanent environmental effects of the dam accounted for 0.07 ± 0.01 of phenotypic variance for the Targhee lambs evaluated in this study (Table 3). In an extensive review of published parameters (Safari et al., 2005), the weighted average heritability of weaning weight was 0.23 ± 0.02 for 15 studies of wool breeds and 0.18 ± 0.02 for 40 studies of dual-purpose breeds. When studies reviewed by Safari et al. (2005) were limited to only those that fitted both direct- and maternal-additive-genetic effects, the average proportions of phenotypic variance accounted for by addi-

Table 2. Means, SD, and CV for weaning weight by sex of lamb.

Lamb sex	Mean, kg	SD, kg[a]	CV, %[a]
Ewe	32.8	5.7	17.2
Ram	35.6	6.5	18.3
Wether	33.8	5.8	17.1

[a] Pooled residual SD and CV for each sex after adjusting for mean effects of year

tive-direct, additive-maternal, and ewe-permanent environmental effects on weaning weight were 0.21, 0.16, and 0.06, respectively, in wool breeds and 0.16, 0.10, and 0.07, respectively, in dual-purpose breeds. The average-genetic correlation between direct and maternal effects on lamb-weaning weight in studies reviewed by Safari et al. (2005) was 0.34, but this association was not significant for the Targhee lambs in the current study. A previous analysis of 32,715 USSES Targhee weaning-weight records for lambs born between 1950 and 1998 yielded estimates of direct and maternal heritabilities of 0.22 ± 0.02 and 0.11± 0.01, respectively, and the proportion of phenotypic variance account for by ewe-permanent-environmental effects was 0.06 ± 0.01 (Hanford et al., 2003). An analysis of 9,736 weaning-weight records for Targhee sheep raised under similar extensive rangeland conditions in Montana yielded estimates of direct and maternal heritabilities and of the proportion of variation accounted for by ewe-permanent environmental effects of 0.12, 0.08, and 0.04, respectively (Borg et al., 2009). An analysis of weaning weights of Targhee lambs from 20 industry flocks participating in the U.S. National Sheep Improvement Program produced estimates of 0.10 and 0.05 for direct and maternal heritabilities, respectively, and the proportion of phenotypic variance accounted for by ewe-permanent-environmental effects was 0.08 (Notter and Hough (1997).

Table 3. (Co)variance components, heritabilities, and genetic and phenotypic correlations between weaning weight and probability of lambing at 1 yr of age in Targhee sheep.

Item	Weaning weight, kg	Probability of lambing
Additive variances	3.29	0.03
Additive maternal variance	2.66	
Dam permanent environmental variance	1.70	
Residual variances	15.90	0.19
Phenotypic variances	23.55	0.22
Heritabilities	0.14 ± 0.02	0.15 ± 0.04
Additive covariance and correlation[a]	-0.07	-0.23 ± 0.18
Phenotypic covariance and correlation[a]	0.40	0.18 ± 0.02

[a] Columns 2 and 3, respectively.

The heritability estimate for probability of lambing at 1 yr of age was 0.15 ± 0.04 (Table 3). Maternal-additive and permanent-environmental effects on probability of lambing were tested in preliminary analyses but were not significant and not included in the final model. Heritability estimates from the literature for measures of reproductive success in ewe lambs bred to lamb for the first time at approximately 1 yr of age are limited and vary widely. In a study of 4,219 ewes of various breeds and crosses, Fogarty et al. (1985) obtained a heritability estimate of 0.04 ± 0.05 for the probability of lambing at 1 yr of age, and the estimate of the heritability of age at first lambing in Dorset sheep was 0.07 ± 0.05 (Lewis et al., 1998). Heritability estimates of 0.12 and 0.14 were reported for age at first lambing in two flocks of Raza Aragonesa ewes (Gabina, 1989). Larger heritabilities for age at first lambing were reported by Iniguez et al. (1986) for Morlam composite ewes (0.31) and Vanimisetti and Notter (2012) for Polypay ewes (0.39). However, sheep in all of these studies were in accelerated-lambing systems, and the applicability of these estimates to sheep managed in extensive rangeland-production systems is not known.

The estimate of the phenotypic correlation between weaning weight and probability of lambing was 0.18 ± 0.02, and the estimated genetic correlation was -0.23 ± 0.18 (Table 3). These results suggest that larger ewe lambs have a somewhat greater probability of lambing at 1 yr of age, but only 3 percent of the phenotypic variation in yearling lambing rate was explained by differences in weaning weight. The genetic association between weaning weight and probability of lambing was small and negative and did not differ significantly from zero. This result suggests that a genetic antagonism between the two traits, if present at all in these data, could be easily managed by placing modest positive selection pressure on both traits.

Conclusion and Implications

Results from this study indicate that genetic variation exists among ewe lambs in weaning weight and in their ability to lamb at 1 yr of age. Ewe lambs with larger weaning weights were predicted to be more likely to lamb at 1 yr of age. This positive association was primarily environmental, indicating that management practices that increase weaning weight would be expected to increase the probability of lambing. By contrast, a small negative-genetic relationship was observed between the two traits, but the relatively low magnitude of the correlation indicates that multiple-trait selection using estimated breeding values would permit concurrent improvement in both weaning weight and the probability of lambing at 1 yr of age.

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