Factors affecting fecal egg counts in periparturient Katahdin ewes and their lambs[1,2,3]

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ABSTRACT: Selection for low fecal egg counts (FEC) can be used to genetically enhance resistance to gastrointestinal nematode parasites in growing lambs, thereby reducing the frequency of use of anthelmintics, facilitating marketing of organic lamb, and reducing the risk of development of anthelmintic resistance by the parasite. Recording of FEC in lambs has, therefore, been incorporated into several national sheep genetic evaluation programs. Ewes in late gestation and early lactation are also vulnerable to parasite infection and commonly experience a periparturient rise in FEC. This study was designed to assess factors associated with the periparturient rise in FEC in Katahdin ewes and associated changes in FEC in their lambs. Data came from 1,487 lambings by 931 Katahdin ewes from 11 farms in the Eastern United States. Fecal egg counts were measured in ewes at approximately 0, 30, and 60 d postpartum and in their lambs at approximately 60, 90, and 120 d of age. Approximately 1,400 lambs were evaluated at each measurement age. Data were analyzed separately for ewes and lambs and also initially analyzed separately for each measurement time. Repeated-measures analyses were then used to evaluate responses across measurement times. In ewes, FEC peaked at approximately 28 d postpartum, and we concluded that informative periparturient FEC could be obtained from 1 wk before until approximately 5 wk after lambing. Yearling ewes had higher FEC than adult ewes ($P < 0.01$), and ewes that nursed twin or triplet lambs had higher FEC than ewes that nursed single lambs ($P < 0.01$). In lambs, FEC increased through approximately 120 d of age. Lambs from yearling ewes and lambs nursed in larger litters were, like their dams, at greater risk of parasitism ($P < 0.05$). Ewes and lambs in these groups would benefit from enhanced monitoring of parasite loads at lambing and in early lactation. Correlations (r) between FEC in lambs at 90 d of age and FEC in ewes at 0, 30, and 60 d postpartum of 0.05 to 0.09 ($P \leq 0.05$) support the presence of a genetic relationship between these 2 indicators of parasite resistance.

Key words: gastrointestinal nematodes, periparturient rise, sheep

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INTRODUCTION

Gastrointestinal nematodes (**GIN**) are a major health problem for small ruminants raised in warm, humid conditions (USDA-APHIS-VS-NAHMS, 2013). In particular, *Haemonchus contortus* is a voracious blood feeder that can cause anemia and death if left untreated in susceptible animals. Anthelmintic resistance is prevalent in the United States (Kaplan, 2004), and alternative methods to control *H. contortus* in both conventional and organic production are, therefore, needed.

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[3]Mention of trade names or commercial products in this manuscript is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA. The USDA is an equal opportunity provider and employer.

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Resistance to GIN parasites is present in many tropical and subtropical sheep breeds (Courtney et al., 1985; Gamble and Zajac, 1992; Amarante et al., 1999). Lambs of the Katahdin breed have been shown to be intermediate in parasite resistance compared with their hair and wool sheep ancestors (Vanimisetti et al., 2004b), and parasite resistance in this breed is a heritable trait that can be improved by selection for low fecal egg counts (**FEC**; Notter, 2013).

Young, growing lambs are most vulnerable to effects of parasitism, but breeding ewes are also especially susceptible to negative effects of parasitism in the period immediately before, at, and following lambing. The impact of the "periparturient rise" in FEC in the ewe at this time has implications for the health of the ewe and risk of infection in susceptible young lambs (Procter and Gibbs, 1968). Merino sheep in Australia selected for increased parasite resistance as lambs (Woolaston et al., 1992) were less susceptible to effects of the periparturient rise (Woolaston, 1992), indicating that a common genetic mechanism is involved in resistance in different classes of animals. Genetic evaluation of FEC in lambs is available in both the U.S. National Sheep Improvement Program (Notter, 2013) and the Australian LAMBPLAN program (MLA, 2004), and U.S. Katahdin sheep breeders have provided leadership for genetic evaluation of lamb FEC. The objective of the current study is to extend existing protocols for evaluation of FEC in lambs by also measuring FEC in periparturient ewes.

MATERIALS AND METHODS

Farm and Animal Description

All animal procedures were approved by the Institutional Animal Care and Use Committee of the Agricultural Research Service (protocol number USDA-ARS-74-F-002) and used the American Dairy Science Association – American Society of Animal Science – Poultry Science Association *Guide for the Care and Use of Agricultural Animals in Research and Teaching* (FASS, 2010). Katahdin sheep farms used in this study were located in the eastern part of the United States. Farms included the USDA ARS Dale Bumpers Small Farms Research Center, Booneville, AR; Virginia Agricultural Experiment Station Southwest Virginia Agricultural Research and Education Center, Glade Spring, VA; Heifer International Heifer Ranch, Perryville, AR; and 9 privately owned farms in Arkansas, Georgia, Maine, New York, and Ohio. Most records were collected in 2009 through 2013, but a few records collected in 2007 were consistent with the experimental design and were included in the data.

Lambings occurred between January and April. All sheep were naturally exposed to GIN on pasture. At each location, fecal samples were collected directly from the rectum to determine FEC according to Whitlock (1948) on ewes near the time of lambing. Additional samples were targeted for collection from ewes at approximately 30 and 60 d postpartum, and FEC were to be determined on their lambs at approximately 60, 90, and 120 d of age. However, samples from ewes at 30 and 60 d postpartum and samples from lambs were not all obtained on every farm or in all years. At each sampling period, a pooled sample of feces from at least 10 animals per farm was cultured to determine the genera of the GIN at the time of collection according to Peña et al. (2002). Ewes and lambs were monitored for evidence of parasitism based on FEC, Faffa Malan Chart (**FAMACHA**) scores (Bath et al., 1996), or other evidence of poor performance and individually treated as necessary to maintain animal welfare.

Ewe records that followed a deworming event, had missing ewe age information, or were associated with atypical lambing dates were removed from the data. The final data set for ewes included 3,572 FEC from 1,487 lambings by 931 ewes. For lambs, records that followed a deworming event and records for lambs with missing dam age information or that were not nursed by their dams were removed from the data. The final data included 4,218 FEC records on 2,271 lambs born in 1,373 litters to 873 Katahdin ewes and sired by 94 rams. Although sampling locations were not uniform in size of operation, there was a representative number of lambs per sire (more than 20). Regional differences should be overcome by all locations using the same breed, connected genotypes, and the presence of *H. contortus* or moderate to high FEC.

Statistical Analysis

Fecal egg counts for both ewes and lambs were transformed as ln(FEC + 25) prior to analysis to assist in normalizing FEC data. Residuals for ewe and lamb FEC at each measurement time after fitting joint effects of farm, year, and ewe management group were used to test for the presence of outliers, which were defined as observations that deviated from the farm–year–management mean by >3 residual SD. No outliers were present following log-transformation of FEC. Means for transformed FEC ($\overline{\mathbf{LFEC}}$) were back-transformed to the original scale as $e^{\overline{\mathrm{LFEC}}} - 25$ for presentation. Standard errors of back-transformed means were derived by assuming that the SE of $\overline{\mathrm{LFEC}}$ were approximately equal to the CV of back-transformed means. Data for ewes and lambs were initially analyzed separately but subsequently combined in a joint analysis to quantify relationships between FEC of ewes and their progeny.

Ewe Data. After editing, 3,592 FEC were available for 1,466 ewes from 11 farms. Of these ewes, 1,352 (92.5%) had records at or near the time of lambing and 743 ewes (50.7%) had records at all 3 scheduled measurement times (0, 30, and 60 d). Most records were collected between 2009 and 2013, but records for 1 farm were also available from 2007. Ewe data included 32 farm–year combinations. Three farms contributed data in all years from 2009 through 2013. The median number of ewes in each farm and year was 39 and ranged from 14 to 116. Management groups, within each farm and year, were further defined as necessary to discriminate among ewes lambing in different seasons or identified by the farm owner as managed in different groups. Lambing season designations were generally assigned to separate ewes that did not lamb in a common 4- to 6-wk period or that were separated by an obvious discontinuity in lambing dates. A total of 57 farm–year–management group combinations were represented in the final ewe data. The median number of ewes per group was 27, with a range of 4 to 94.

Records were initially analyzed separately for each measurement time. The model for FEC taken at or near the time of lambing included fixed effects of farm, litter size, ewe age, and the ewe age × litter size interaction; continuous linear and quadratic effects of number of days since lambing at measurement; and random effects of year and season (nested within farm), management group (nested within year, season, and farm), and ewe. Litter size at birth was classified as 1, 2, or 3. Records for a small number of ewes with quadruplet births were combined with those of triplet-bearing ewes. Ewe age was defined by age at lambing in years, with 7 classes. Ewes that lambed at >7 yr of age (42 of 1,487 total lambings) were combined with the 7-yr-old ewe group. Patterns of change in FEC with changes in ewe age were further assessed by fitting orthogonal linear and quadratic contrasts among ewe age class means. Variance components for random ewe and residual effects ($\sigma^2_{E_i}$ and $\sigma^2_{R_i}$, respectively) were used to estimate the repeatability of ewe FEC at the *i*th measurement time in different years as $t_i = \sigma^2_{E_i}/(\sigma^2_{E_i} + \sigma^2_{R_i})$. In models for FEC at 30 and 60 d after lambing, the effect of litter size at birth was replaced with the joint effect of number of lambs born (**i**) and number of lamb reared (**j**) with 5 classes (ij = 11, 21, 22, 32, and 33. Residuals from these models for ewes with FEC at >1 measurement time were used to determine correlations among measurements taken on the same ewes at different times within the same measurement year.

Based on results of analyses conducted within each measurement time (discussed below), a final repeated-measures analysis of ewe FEC was conducted across all measurement times. This model included fixed effects of farm, number of lambs reared, and ewe age; continuous linear and quadratic effects of time since lambing; and random effects of year and season (nested within farm), management group (nested within year, season, and farm), ewe (nested within farm), and litter (modeled as ewe × year × season interaction and nested within farms).

Lamb Data. After removing records for 8 lambs with missing sire information, 4,218 progeny FEC were available for 2,271 lambs in 11 farms and representing all 32 farm–year combinations. Records were available at all sampling times (60, 90, and 120 d of age) for 270 lambs (11.9%), but most lambs (1,677; 73.8%) had records for at least 2 sampling times. Numbers of lambs with records at 60, 90, and 120 d were 1,024 (45.1%), 1,798 (79.2%), and 1,396 (61.5%).

Lamb records were also initially analyzed separately for each measurement time. The initial model included fixed effects of farm, lamb birth-rearing type, dam age, lamb sex, and the ewe age × lamb birth-rearing type interaction; continuous linear and quadratic effects of lamb age within each measurement time; and random effects of year and season (nested within farm), ewe management group (nested within farm, year, and season), sire and dam of the ewe, year–season × dam interaction, and residual. Lamb sex was coded as ram or ewe; no wether lambs were present in the final data sets. Patterns of change in FEC with changes in dam age were further assessed by fitting orthogonal linear and quadratic contrasts among dam age class means. Orthogonal contrasts were also used to test linear and quadratic effects of litter size on lamb FEC for birth-rearing classes 1–1, 2–2, and 3–3. Residuals from these models for lambs with FEC at >1 measurement age were used to determine correlations among measurements taken at different ages within the same measurement year. Variance components for effects of lamb sire ($\sigma^2_{S_j}$), dam ($\sigma^2_{D_j}$), year–season × dam interaction ($\sigma^2_{I_j}$), and residual ($\sigma^2_{Y_j}$) at lamb age *j* were used to estimate phenotypic variances within management groups, seasons, years, and farms as $\sigma^2_{P_j} = (\sigma^2_{S_j} + \sigma^2_{D_j} + \sigma^2_{I_j} + \sigma^2_{Y_j})$ and to subsequently estimate, for each lamb measurement age, heritability ($h^2_j = 4\sigma^2_{S_j}/\sigma^2_{P_j}$), repeatability of dam effects across lambing years ($t_{D_j} = \sigma^2_{D_j}/\sigma^2_{P_j}$), and full-sib littermate correlation [$t_{FS_j} = (\sigma^2_{S_j} + \sigma^2_{D_j} + \sigma^2_{I_j})/\sigma^2_{P_j}$].

RESULTS

Fecal Cultures

The predominant genera of GIN cultured were *H. contortus* and *Trichostrongylus* spp. Other genera that were sometimes but not always present were *Cooperia* spp., *Oesophagostomum* spp., and *Teladorsagia* spp.

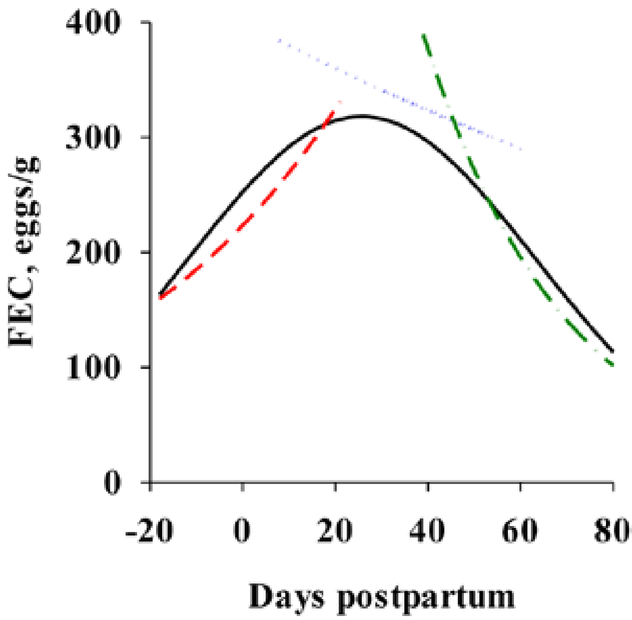

Figure 1. Changes in ewe fecal egg counts (FEC) over time for adult ewes (3 through 5 yr old) nursing twin or triplet lambs. Patterns were derived from linear and quadratic regressions of log-transformed ewe FEC on days postpartum; values were back-transformed to the original scale for presentation. The overall linear and quadratic curve (both $P < 0.001$; solid black line) was derived from a repeated-measures analysis of ewe FEC across all measurement times. Effects of days postpartum were positive at d 0 ($P = 0.05$; red dashed line) and negative at d 60 ($P < 0.001$; green dashed/dotted line) but were not affected by days postpartum at d 30 ($P = 0.58$; blue short dashed line). Based on the overall curve, periparturient ewe FEC reached a maximum at 28 d postpartum.

(less than 1% on 1 farm). *Strongyloides* spp. were present in lambs on 3 farms and ewes on one of those farms. *Haemonchus contortus* was cultured in all months of the study and on all farms.

Ewe Fecal Egg Counts

Effects of time from lambing to measurement of FEC are shown within each measurement time in Fig. 1 following back-transformation to the original FEC scale. Effects of time since lambing were positive ($P = 0.05$) for FEC taken around the time of lambing, not different from 0 ($P = 0.58$) for FEC taken around 30 d postpartum, and negative ($P < 0.001$) for FEC taken around 60 d postpartum. Results taken around the time of lambing, therefore, encompassed the period of the periparturient rise in FEC. If the range of observation times was restricted to between 7 d before and 21 d after lambing, no effect of time to lambing was present ($P = 0.30$), suggesting that measurements taken within this range were not strongly affected by time-related changes in FEC. Declines in FEC with increasing days postpartum for ewes measured between 39 and 89 d postpartum suggested that ewes were beginning to bring effects of the periparturient rise under control by this time. Results of the repeated-measures analysis, shown by the continuous curve in Fig. 1, indicated that FEC in periparturient ewes reached a maximum at 28 d postpartum and subsequently declined sharply, in association with linear and quadratic effects of postpartum interval on FEC (both $P < 0.001$). These results suggest that measurements of FEC designed to characterize the periparturient rise should be collected from within approximately 7 d of lambing until at most 4 to 6 wk postpartum.

Ewe age effects on FEC in periparturient ewes were significant ($P < 0.05$) at all measurement times (Fig. 2). Yearling ewes were particularly vulnerable to effects of parasitism, especially before 60 d postpartum. A quadratic effect of ewe age was observed around the time of lambing ($P < 0.05$), with elevated FEC in older ewes as well as yearling ewes. However, by 30 and 60 d postpartum, this observed relationship had changed to a simple linear effect of ewe age ($P < 0.05$), suggesting more rapid recovery from initial increases in FEC in older ewes.

Ewes that delivered 2 or more lambs were more vulnerable to the periparturient rise, with higher FEC at or near the time of lambing ($P < 0.001$; Fig. 3). At 30 d postpartum, FEC in lactating ewes was primarily associated with the number of lambs suckled and was much higher ($P < 0.001$) for ewes that were nursing 2 or 3 lambs. By 60 d postpartum, mean FEC levels had declined for ewes in all birth-rearing classes, but ewes nursing single lambs still had lower FEC than ewes nursing twins ($P = 0.006$).

Correlations between FEC in ewes at different times within the same year were moderate and highly significant ($P < 0.001$), ranging from 0.43 between measurements taken at 0 and 30 d postpartum and 0.42 for measurements taken at 30 and 60 d postpartum to 0.34 for measurements taken at 0 and 60 d postpartum. Therefore, despite the relatively dynamic patterns of change in ewe FEC during early lactation (Fig. 1), differences in FEC among ewes were relatively consistent throughout the first 60 d of lactation. Repeatabilities across years for ewe FEC were likewise positive at each measurement time, ranging from 0.41 at d 0 to 0.35 at d 30 and 0.27 at d 60 (all $P < 0.001$) and were, therefore, similar to correlations observed among FEC values at different times within the same measurement year. The FEC in periparturient ewes is, therefore, a repeatable characteristic, and removal of ewes with high periparturient FEC from the farm was expected to be effective in reducing future parasite loads.

Lamb Fecal Egg Counts

Significant linear and quadratic effects of lamb age on FEC were observed in lambs evaluated at average ages of 60 ($P = 0.003$ and $P = 0.01$, respectively) and 90 d ($P = 0.02$ and $P = 0.03$, respectively; Fig. 4). At 60 d,

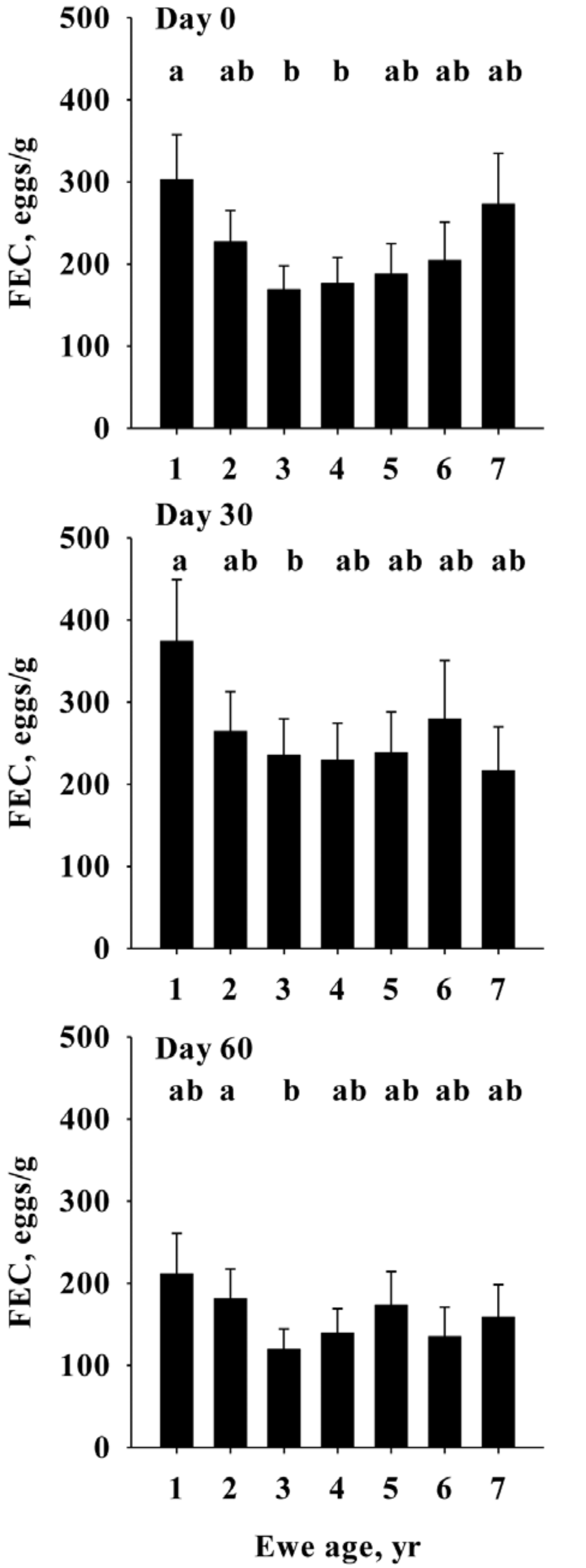

Figure 2. Least squares means and SE for effects of ewe age on ewe fecal egg counts (FEC) at 0, 30, and 60 d postpartum. Results were based on separate analyses at each sampling time. Values for FEC were log-transformed for analysis, but means were back-transformed to the original scale for presentation. [a,b]Lowercase letters denote significant differences at $P < 0.05$. A quadratic effect ($P < 0.05$) of ewe age was present at Day 0. Linear effects of ewe age ($P < 0.05$) were observed at 30 and 60 d postpartum.

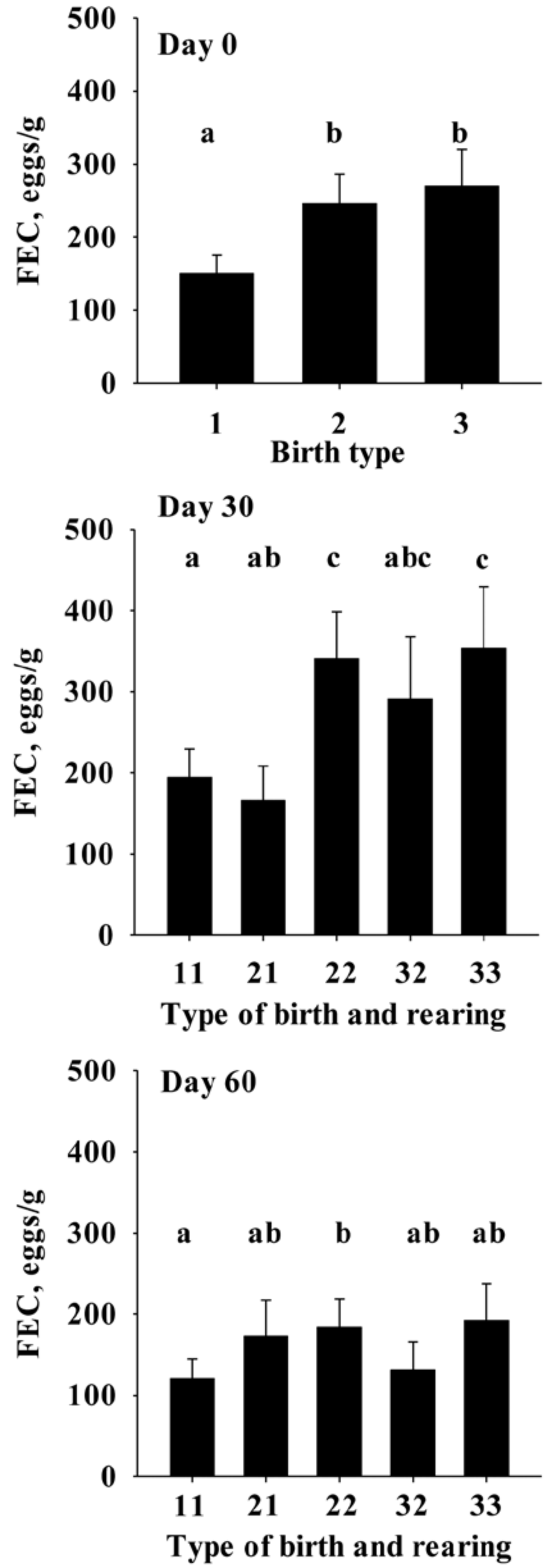

Figure 3. Least squares means and SE for effects of birth type (single, twin, or triplet) on ewe fecal egg counts (FEC) at lambing (Day 0) and effects of numbers of lambs born and reared on FEC of lactating ewes at 30 and 60 d postpartum (e.g., 11 = born single and reared single, 21 = born twin and raised single, etc.). Results were based on separate analyses at each sampling time. Values for FEC were log-transformed for analysis, but means were back-transformed to the original scale for presentation. [a–c]Lowercase letters denote significant differences at $P < 0.05$. Orthogonal contrasts indicated that ewes that delivered 2 or more lambs had higher FEC at or near the time of lambing ($P < 0.001$) and that FEC were much higher ($P < 0.001$) at 30 d and somewhat higher ($P = 0.006$) at 60 d for ewes that nursed 2 or 3 lambs.

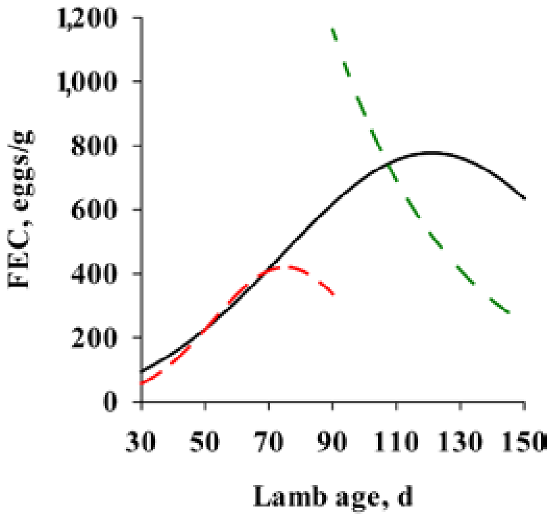

Figure 4. Changes in lamb fecal egg counts (FEC) with increasing lamb age. Patterns for each measurement time were derived from linear and quadratic regressions of log-transformed lamb FEC on age at each time; values were back-transformed to the original scale for presentation. The overall linear and quadratic curve was derived from a repeated-measures analysis of lamb FEC across all ages (solid black line). Both linear and quadratic effects of lamb age were significant at average ages of 60 ($P \leq 0.01$; red dashed line) and 90 d ($P \leq 0.03$; blue dotted line), and in the repeated-measures analysis (both $P < 0.001$), but only the linear effect was significant at 120 d ($P < 0.001$; green dashed/dotted line). Based on the overall curve, lamb FEC reached a maximum at 121 d of age.

FEC initially rapidly increased with increases in lamb age, likely in association with greater forage intake in older lambs, but reached a maximum value by 75 d of age and subsequently declined. In contrast to results observed at an average age of 60 d, by 90 d of age, FEC were higher for the youngest lambs, presumably reflecting greater opportunity for infection at this average age and reduced resilience to infection in younger lambs. At an average age of 120 d, FEC linearly declined ($P < 0.001$) as lamb age increased, now presumably mainly reflecting age-associated differences in resilience of lambs to infection. Linear and quadratic effects of lamb age (both $P < 0.001$) were observed in the repeated-measures analysis. Results of this analysis indicated that FEC in growing lambs reached a maximum at 121 d of age and subsequently declined.

Dam age effects on progeny FEC were not significant at 60 ($P = 0.74$) or 120 d of age ($P = 0.47$) but approached significance ($P = 0.09$) at 90 d, with lambs raised by yearling ewes most susceptible to infection (Fig. 5). Orthogonal contrasts among dam age classes revealed a quadratic effect of dam age on lamb FEC at both 90 ($P = 0.02$) and 120 d of age ($P = 0.07$). Effects of dam age on lamb FEC were, therefore, broadly similar to effects of ewe age on ewe FEC.

At both 60 and 90 d, lambs born and reared as singles had lower FEC than lambs born and reared as triplets; lambs born and reared as twins were inter-

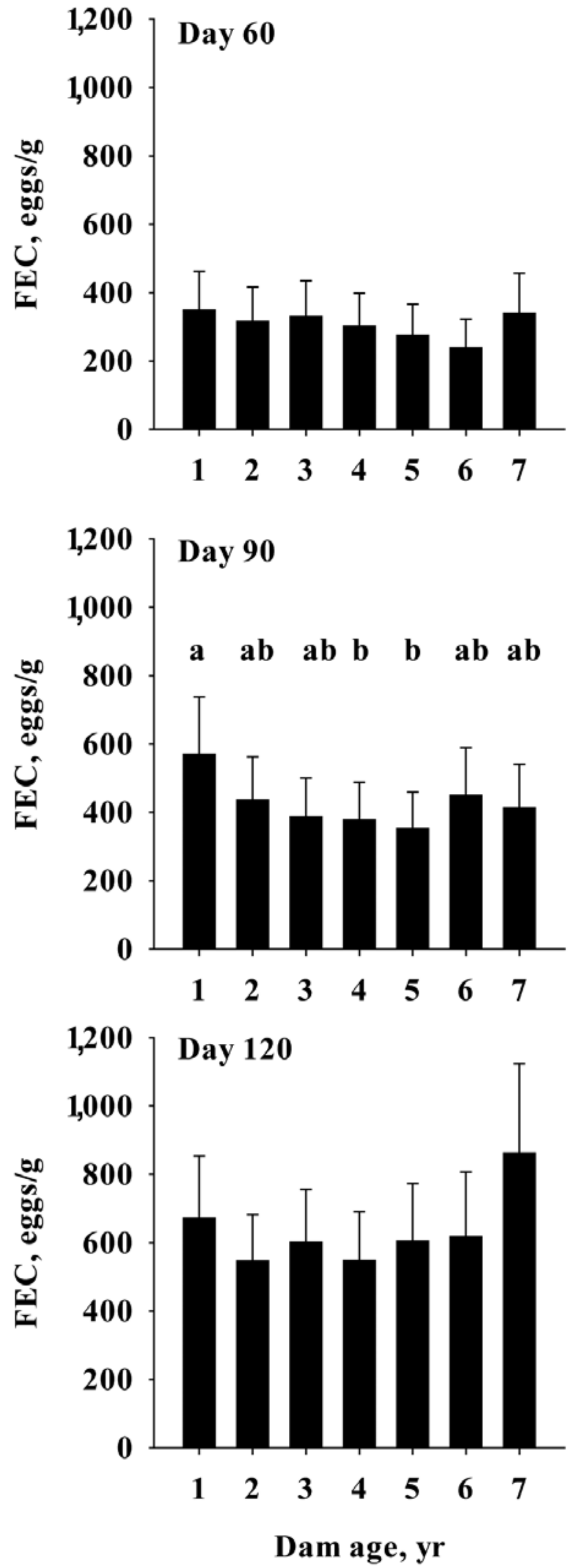

Figure 5. Least squares means and SE for effects of dam age on lamb fecal egg counts (FEC) at 60, 90, and 120 d of age. Results were based on separate analyses at each sampling time. Values for FEC were log-transformed for analysis, but means were back-transformed to the original scale for presentation. [a,b]Lowercase letters denote significant differences at $P < 0.10$. Orthogonal contrasts among dam age classes revealed a quadratic effect of dam age on lamb FEC at both 90 ($P = 0.02$) and 120 d of age ($P = 0.07$).

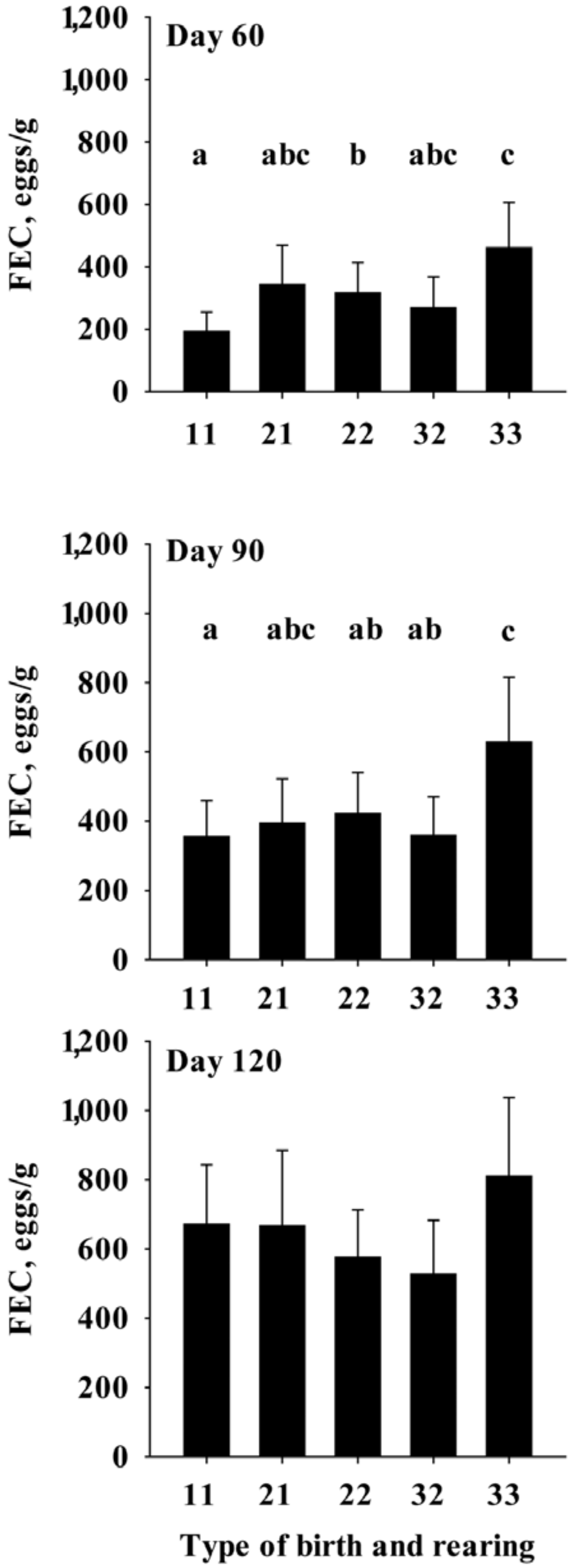

Figure 6. Least squares means and SE for effects of numbers of lambs born and reared by the dam on lamb fecal egg counts (FEC) at 60, 90, and 120 d of age (e.g., 11 = born single and reared single, 21 = born twin and raised single, etc.). Results were based on separate analyses at each sampling time. Values for FEC were log-transformed for analysis, but means were back-transformed to the original scale for presentation. [a–c]Lowercase letters denote significant differences at $P < 0.05$. At both 60 and 90 d, lambs born and reared as singles had lower FEC than lambs born and reared as triplets, and lambs born and reared as twins were intermediate, with significant linear trends ($P < 0.001$) in FEC with increasing litter size among these 3 groups of lambs.

mediate, with a significant linear trend ($P < 0.001$) in FEC with increasing litter size among these 3 groups of lambs (Fig. 6). The less numerous lambs born as twins but raised as singles or born as triplets but reared as twins did not show consistent FEC, and no effect of lamb type of birth and rearing was observed by 120 d of age ($P = 0.39$).

Correlations among FEC measurements in lambs at different ages within the same measurement year were moderate and positive at 60 and 90 d of age ($r = 0.33$, $P < 0.001$) and at 90 and 120 d of age ($r = 0.27$, $P < 0.001$) but were smaller for measurements taken at 30 and 120 d of age ($r = 0.09$, $P < 0.10$). Consistency among measurements of FEC in lambs, therefore, declined as time between measurements increased. The magnitude of observed sire effects on lamb FEC varied considerably among measurement times. Heritability estimates increased from 0.15 at 30 d ($P = 0.04$) to 0.46 at 90 d ($P < 0.001$) but decreased to only 0.06 ($P = 0.19$) at 120 d. Repeatability of ewe effects, based on correlations between FEC in lambs produced by the same ewes in different years, were generally small, accounting for 4, 6, and 2% of phenotypic variance at 60, 90, and 120 d of age, respectively, and were significant only at 90 d of age ($P = 0.04$). However, correlations between FEC in full-sib littermate lambs born in the same year were reasonably large, ranging from 0.18 at 60 d ($P = 0.07$) to 0.22 at 90 d ($P = 0.18$) and 0.28 at 120 d ($P < 0.001$). The resemblance among full-sib littermate lambs represents combined effects of shared genes from sire and dam, a common maternal effect of the dam, and any other shared environmental effects of littermate lambs. Results of the repeated-measures analysis provided estimates of heritability, repeatability of ewe effects, and the correlation between full-sib lambs across the full measurement period of 0.17, 0.03, and 0.13, respectively. Estimates of heritability and ewe repeatability were consistent with simple averages of values obtained at the individual measurement times, but the full-sib correlation in the combined data was lower than expected, suggesting a more dynamic relationship among FEC in full-sib littermate lambs across measurement times.

Resemblance between Fecal Egg Counts of Ewes and Their Lambs

Correlations between FEC measurements in ewes and the average FEC for their lambs at each pair of measurement times are shown in Table 1. A majority of the correlations were positive, but significant relationships were observed only for the 90-d lamb measurements, and the maximum correlation, between ewe FEC at 30 d postpartum and lamb FEC at 90 d of age, was 0.09 ($P < 0.001$).

Table 1. Correlation coefficients between ewe and lamb fecal egg counts (FEC) at various times postpartum for ewes and at various ages for lambs

Ewe FEC at	Lamb FEC at age		
postpartum day	60 d	90 d	120 d
0	0.00	0.05*	0.03
30	−0.02	0.09***	0.03
60	0.03	0.06*	0.02

*$P < 0.05$; ***$P < 0.001$.

DISCUSSION

Multidrug anthelmintic resistance is highly prevalent in the United States (Kaplan, 2004; Howell et al., 2008), with complete anthelmintic resistance present on many farms (R. Kaplan, The University of Georgia, Athens, personal communication). Newer anthelmintics such as monepantel (Kaminsky et al., 2009; Mason et al., 2009) are not yet available in the United States, and resistance to monepantel has already been reported in New Zealand (Scott et al., 2013). Some alternative methods of control for *H. contortus* in both conventional and organic production are good nutrition, rotational grazing, multispecies grazing, and use of resistant breeds (Terrill et al., 2012). Some of these methods are not practical for all farms and more information is needed for integration to maximize control and production. In addition to the risks of mortality and morbidity from parasite infection, once an animal is treated with a chemical anthelmintic, organic premiums are lost because the animal must be sold in the conventional market. "Certification standards established under the National Organic Program (USDA Agricultural Marketing Service, 2000, 2012) approved fenbendazole, ivermectin, and moxidectin as paraciticides for use in breeding animals. Resistance by parasites to all of these drugs is widespread (Miller and Craig, 1996; Terrill et al., 2001; Mortensen et al., 2003; Howell et al., 2008), including all research sites and many of the producer farms in this project.

Fecal egg counts in growing lambs have been shown to be under quantitative genetic control, and FEC records in lambs have been used to allow genetic evaluation of parasite resistance in sheep (Brown and Fogarty, 2016). Recording of FEC in growing lambs is challenging. Young lambs are particularly vulnerable to effects of parasitism (Woolaston and Piper, 1996), but if selection is to be effective, the parasite challenge must be sufficient to make resulting FEC measurements informative for identification of differences among lambs in parasite resistance. Careful monitoring of parasite levels and prompt treatment of potentially parasitized lambs following data collection is, therefore, necessary to obtain useful information but also to minimize mortality and morbidity in the lambs.

Collection of FEC data on adult ewes has been proposed as an alternative to collecting data on growing lambs. Adult ewes are less susceptible to negative effects of parasitism and better able to cope with infection. However, adult ewes also generally have lower FEC than lambs sampled at the same times and on the same pastures. Vanimisetti et al. (2004a) reported that adult ewes, sampled following weaning of their lambs and after artificial parasite challenge, had much lower FEC than their lambs. The FEC were heritable in both lambs and ewes (0.19 and 0.31, respectively), but no correlation was observed between mean FEC in lambs and their dams. These results, and considerations associated with the generally accepted progression of infection in adult sheep, suggest that FEC from nonlactating adult ewes may have limited value as indicators of parasite resistance in growing lambs.

The periparturient period, from shortly before until a few weeks after lambing, is, however, a time when ewes are particularly vulnerable to parasite infection. The periparturient rise in FEC commonly occurs at this time and has been extensively studied (Procter and Gibbs, 1968), but mechanisms that drive this increase in FEC remain poorly understood. Little information is available regarding genetic control of parasite resistance at this time. Deworming of periparturient ewes is widely recommended, even in breeds that have substantial levels of parasite resistance. However, on farms that have relatively short breeding seasons and with ewes that are observed closely around the time of lambing, collection of data on the periparturient rise is possible without particular risk of detrimental effects of infection. For example, if ewes are observed closely or "jugged" (i.e., confined with their lambs for 1 to 3 d) at lambing, ewes can be selectively dewormed as required (Kaplan et al., 2004) following collection of a fecal sample to both provide information on parasite resistance and protect ewes and their lambs from infection.

Merino ewes from lines that were divergently selected for FEC in growing lambs exhibited corresponding differences in FEC in periparturient ewes, mainly in association with more rapid recovery from the initial rise in FEC (Woolaston, 1992). Parasite resistance in periparturient ewes is an acquired immune response. In contrast, and depending on the age at measurement, expression of parasite resistance in growing lambs reflects the development of immune competence and involves both innate immunity to the parasite and acquisition of immunity following initial exposure. Results of Woolaston (1992) support the concept that similar mechanisms control parasite resistance in periparturient ewes and growing lambs and that information from both classes of animals can be combined to enhance selection responses in overall parasite resistance in the flock. However, results in Merino ewes in Uruguay indicated that heritabilities of FEC were considerably higher in lambs than in periparturient ewes and that indirect selection based on lamb FEC would be more effective than direct selection based on ewe FEC in limiting the periparturient rise (Goldberg et al., 2012).

Results of the current study involved Katahdin ewes that lambed in January through April. Across the total set of ewes, only 22 ewes (0.05%) exhibited sufficient evidence of parasitism to require deworming. Fecal samples were obtained from 18 d before to 21 d after lambing, and when data encompassing this entire range were included in the analysis, a significant positive relationship was observed between the time of sampling and ewe FEC. This result suggests that ewes sampled at 1 to 3 wk before lambing had lower FEC than ewes sampled later in the periparturient period. However, when the range of sampling times was limited to −7 to 35 d from lambing, no significant relationship was observed between FEC and time of sampling, suggesting that ewes sampled in this period provided samples that were informative regarding the magnitude of the periparturient rise. Ewes sampled at approximately 30 d postpartum (range of 8 to 53 d postpartum) likewise exhibited no relationship between sampling time and FEC, again suggesting that samples taken during this period would be representative of parasite resistance in early lactation. In contrast, in ewes sampled at approximately 60 d postpartum (range of 39 to 80 d postpartum), a strong negative relationship was observed between FEC and time postpartum, suggesting that even though the parasite challenge on pastures was increased as the grazing season progressed, ewes were able to bring the periparturient infection under control and reduce parasite burdens. When ewe FEC were analyzed across all measurement times in a repeated-measures analysis, FEC increased in a quadratic manner over time and reached a predicted maximum at 28 d postpartum. These analyses suggest that assessment of periparturient ewe FEC can be accomplished between approximately 7 d before and 30 to 35 d after lambing. The preferred sampling time will depend on the level of housing and access to the ewes, the duration of the lambing season (to facilitate or complicate sampling before lambing), and the incidence and severity of parasitism (and, therefore, both the ability to collect meaningful information at or shortly before lambing and the risk of negative phenotypic effects) in lactating ewes and their lambs.

Despite the small absolute values observed for the correlations between FEC in ewes and their lambs, the associations were generally consistent with expectations. The expected correlation between ewe and lamb FEC measurements taken at the *i*th day of lactation and the *j*th lamb age is $0.5\, h_{E_i} h_{L_j} r_{G_{ij}}$, in which h_{E_i} and h_{L_j} are the square roots of the heritabilities for ewe and lamb FEC at these times and $r_{G_{ij}}$ is the genetic correlation between them. Therefore, if heritabilities for ewe and lamb FEC were both 0.4, an observed correlation of 0.09 corresponds to a realized genetic correlation between ewe FEC at 30 d postpartum and lamb FEC at 90 d of age of 0.45. Alternatively, if $r_{G_{ij}} = 0.7$, then observed correlations of 0.09 and 0.05 correspond to heritability estimates of 0.26 and 0.14, respectively. These hypothetical values for h_{E_i}, h_{L_j}, and $r_{G_{ij}}$ are reasonably consistent with the literature (Safari et al., 2005; Goldberg et al., 2012; Brown and Fogarty, 2016), given the limited number of observations available in this study.

Factors that increase vulnerability to negative effects of parasitism in both ewes and lambs include the age of the ewe, with greater risk of parasitism in yearling ewes and their lambs, and the number of lambs being suckled, with larger litters increasing vulnerability of both ewes and lambs. Particular attention to these vulnerable groups of animals, perhaps including separate penning, provision of better nutrition (through either access to better pastures or supplemental feeding), more frequent assessments of parasite infection status, or selective deworming of animals representing these groups, are indicated for farms where parasite challenge is high, even for relatively resistant breeds such as the Katahdin. Selection for resistance during the periparturient rise in the ewe has the potential to reduce pasture contamination, which is especially important if using a susceptible terminal sire breed where offspring will be more susceptible to GIN.

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