A novel measure of ewe efficiency for breeding and benchmarking purposes[1]

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ABSTRACT: Ewe efficiency has traditionally been defined as the ratio of litter weight to ewe weight; given the statistical properties of ratio traits, an alternative strategy is proposed in the present study. The concept of using the deviation in performance of an animal from the population norm has grown in popularity as a measure of animal-level efficiency. The objective of the present study was to define novel measures of efficiency for sheep, which considers the combined weight of a litter of lambs relative to the weight of their dam, and vice versa. Two novel traits, representing the deviation in total litter weight at 40 d (DEV40L) or weaning (DEVweanL), were calculated as the residuals of a statistical model, with litter weight as the dependent variable and with the fixed effects of litter rearing size, contemporary group, and ewe weight. The deviation in ewe weight at 40-d postlambing (DEV40E) or weaning (DEVweanE) was derived using a similar approach but with ewe weight and litter weight interchanged as the dependent variable. Variance components for each trait were estimated by first deriving the litter or ewe weight deviation phenotype and subsequently estimating the variance components. The phenotypic SD in DEV40L and DEVweanL was 8.46 and 15.37 kg, respectively; the mean litter weight at 40 d and weaning was 30.97 and 47.68 kg, respectively. The genetic SD and heritability for DEV40L was 2.65 kg and 0.12, respectively. For DEVweanL, the genetic SD and heritability was 4.94 kg and 0.13, respectively. The average ewe weight at 40-d postlambing and at weaning was 66.43 and 66.87 kg, respectively. The genetic SD and heritability for DEV40E was 4.33 kg and 0.24, respectively. The heritability estimated for DEVweanE was 0.31. The traits derived in the present study may be useful not only for phenotypic benchmarking of ewes within flock on performance but also for benchmarking flocks against each other; furthermore, the extent of genetic variability in all traits, coupled with the fact that the data required to generate these novel phenotypes are usually readily available, signals huge potential within sheep breeding programs.

Key words: efficiency, genetics, sheep, weight

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INTRODUCTION

The importance of efficient meat production systems is intensifying in light of the desire for long-term global food security. Efficiency, either at an animal (Hegarty et al., 2007; Berry and Crowley, 2013) or at a system (Leymaster, 2002; Berry et al., 2015) level has traditionally been represented by the ratio of outputs to inputs, including the ratio of litter weight to ewe weight (Lobo et al., 2012). The statistical properties of ratio traits (Gunsett, 1984) necessitate an alternative strategy to simply litter weight as a ratio of ewe weight.

More recently, the concept of using the deviation in performance of an animal from the

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population norm has grown in popularity; such traits include residual feed intake, residual daily gain (Koch et al., 1963), and residual intake and gain (Berry and Crowley, 2013). The hypotheses underpinning these residual-based statistics are that animals that perform better than the mean of their population contemporaries are deemed to be more efficient. One of the merits of the residual-based traits is that there is an obvious biological interpretation of the emanating value as it is presented in the units of the dependent variable.

Procuring actual feed intake records on individual animals is resource intensive, and even measuring group-level (e.g., flock) feed intake, especially in extensive sheep production systems, can also be challenging. Therefore, measures of efficiency on an animal or group level will probably be void of feed intake data. In beef production systems, up to 75% of the total dietary energy in the cow herd is used for maintenance (Montaño-Bermudez et al., 1990). Therefore, representing any output parameter as a function of the maintenance requirements (approximated from body weight) of the herd or flock could be a useful proxy for efficiency.

Hence, the objective of the present study was to define novel measures of efficiency for sheep, which consider the total weight of a litter of lambs relative to the weight of the dam, and vice versa.

MATERIALS AND METHODS

Data

A total of 101,216 weight records from 42,965 ewes collected from 624 flocks between the years 2008 and 2017, inclusive were extracted from the Irish national database hosted by Sheep Ireland (http://www.sheep.ie). An additional 174,547 lamb weight observations at approximately 40 d of age and a further 219,381 lamb weaning weight observations between the years 2008 and 2017, inclusive were also available. Ewe weight was defined as the weight of a female who had at least one recorded lambing event; only recorded ewe weights between 45 and 120 kg were retained. Lamb weight recorded at approximately 40 d (hereon referred to as 40-d weight) was defined in the present study as the weight taken between 20 and 65 d of age; only records of lambs weighing between 12 and 32 kg were retained. Lamb weaning weight was defined as the weight recorded between 66 and 120 d of age; only weights between 20 and 55 kg were retained. In the present study, weight records relating to both the ewe and the lamb were only retained where both the ewe and her litter were weighed on the same calendar day. The combined litter weight at 40 d and at weaning was generated by summing the weights of all litter mates. This resulted in the retention of 6,776 ewe and litter weights (10,186 individual lamb weights) recorded at 40 d and a further 6,469 ewe and litter weights (9,334 individual lamb weights) recorded at weaning.

Data were also available on date of birth, ewe parity, breed composition, and the ancestry of each ewe and lamb. Records were discarded if the flock of birth for the litter was unknown, or either the sire or dam (lambs only) was unknown. The breed proportion of each animal for the 5 major performance recording breeds in Ireland: Belclare, Charollais, Suffolk, Texel, and Vendeen were calculated. Only lambs and ewes with ≥50% of their breed fraction known were considered in the analysis. Ewes with no information on parity number were discarded, as were records from parities >10; ewe parity was subsequently categorized as 1, 2, 3, 4, or ≥5. Age of the dam at first lambing was categorized as lambing either 1) between 8 and 18 mo of age or 2) between ≥18 and 28 mo of age.

Birth type of the lamb was defined as the recorded number of lambs born (alive or dead) per lambing event; only birth types between 1 (singles) and 4 (quadruplets) were retained for analysis. Litter rearing size was defined as the number of lambs reared in the litter (including the lamb itself) at day 7 postlambing; only litter rearing sizes between 1 and 3 were retained. Litter (and ewe) weight records were discarded for litters where 1 or more lamb(s) had been cross-fostered onto a surrogate ewe. If 1 or more of the lambs, however, died before 7 d of age, the combined weight of the remaining lambs was used; the exception was the case were no live lambs existed, in which case it was not considered further.

Heterosis and recombination loss coefficients were calculated for each ewe and litter as $1-\sum_{i=1}^{n}\text{sire}_i \cdot \text{dam}_i$ and $1-\sum_{i=1}^{n}\frac{\text{sire}_i^{\,2} \cdot \text{dam}_i^{\,2}}{2}$, respectively, where sire_i and dam_i are the proportion of breed *i* in the sire and dam, respectively. Heterosis and recombination loss coefficients were subsequently grouped into distinct classes based on the frequency distribution of the respective coefficients. For heterosis, 3 distinct classes were formed: less than 10%, 10% to 99%, and 100%. For recombination loss, 2 classes were formed: less than 10% and 10% to 50%.

Each ewe and litter weight combination for 40-d weight and weaning weight was allocated to a contemporary group of flock-date of weighing. Only records from contemporary groups with at least 5 records were retained. Following all edits, 4,838 ewe and litter weights recorded at 40 d (7,707 individual lamb weight records) and 4,817 ewe and litter weights recorded at weaning (7,259 individual lamb records) remained. A total of 2,189 ewe and litters had a weight recorded at both 40 d and at weaning. The proportion of purebred and crossbred litters was 17% and 83% in the 40-d weight dataset and 30% and 70% in the weaning weight dataset. The most common crosses within the crossbred population were as follows: Suffolk (sire breed) × Belclare (dam breed), Charollais × Suffolk, Texel × Belclare, Suffolk × Belclare, and Suffolk × Blackface Mountain.

Phenotype Creation

A number of novel phenotypes were created to represent the combined weight of a litter relative to the respective weight of the ewe at the same time point, or vice versa. For litter weight, 2 traits were created that represented the deviation in the weight of the litter at either 40 d (phenotype termed deviation in litter 40-d weight; **DEV40L**) or weaning (phenotype termed deviation in litter weaning weight; **DEVweanL**). In addition, for ewe weight, 2 traits representing the deviation in the weight of the ewe at either 40-d postlambing (**DEV40E**) or at weaning (**DEVweanE**) was also constructed.

For the derivation of DEV40L, the following model was initially fitted:

$$\text{LitterWT40}_{ij} = \mu + \text{CG}_i + \beta_1\text{EweWT40} + \text{Litter}_j{*}\beta_2\text{Age} + e_{ij}$$

where LitterWT40_{ij} = litter weight at 40 d, μ = the population mean, CG_i = the fixed effect of contemporary group (i = 1,…, 113), EweWT40 = the covariate effect of ewe weight recorded at 40 d and β_1 = the associated regression coefficient, $\text{Litter}_j{*}\beta_1\text{Age}$ = the interaction between the fixed effect of litter rearing size (j = single, twin, or triplet) and the continuous effect of litter age at weighing relative to 40 d and β_2 = the associated regression coefficient, and e_{ij} = the random error $[\text{N}(0, \text{I}\sigma_e^2)]$. DEV40L was subsequently derived by subtracting from LitterWT40, the estimated model regression coefficient for EweWT40 times the respective ewe weight (i.e., EweWT40); for each litter of a given size, the appropriate age adjustment to 40-d equivalent was used based on the model regression coefficient for that litter size and the age of the litter relative to 40 d. The model fixed effects solutions for litter size itself or contemporary group were therefore not used when adjusting 40-d weight to create DEV40L. A similar approach was used in the creation of DEVweanL except where the dependent variable of weight at d 40 was replaced by weaning weight, EweWT40 was the weight of the ewe at weaning, and the covariate of age was relative to d 100 rather than d 40.

The deviation in ewe weight at d 40 post lambing was derived as the residuals from the following model:

$$\text{EweWT40}_{ij} = \mu + \text{CG}_i + \beta_1\text{LitterWT40} + \text{Litter}_j{*}\beta_2\text{Days} + e_{ij}$$

where EweWT40_{ij} = ewe weight on d 40 post lambing, μ = the population mean, CG_i = the fixed effect of contemporary group (i = 1,…, 113), LitterWT40 = the covariate effect of litter weight recorded at d 40 post lambing and β_1 = the associated regression coefficient, $\text{Litter}_j{*}\beta_2\text{Days}$ = the interaction between the fixed effect of litter rearing size (j = single, twin, or triplet), and the continuous effect of days post lambing relative to d 40 and β_2 = the associated regression coefficient, and e_{ij} = the random error $[\text{N}(0, \text{I}\sigma_e^2)]$. The deviation in ewe weight at d 40 postlambing (hereon referred to as DEV40E) was derived by subtracting from EweWT40, the LitterWT40 model solution times the respective litter weight; for each litter of a given size, the appropriate age adjustment to d 40 postlambing equivalent was used based on the model regression coefficient for that litter size and the days postlambing of the ewe relative to d 40 postlambing. A similar approach was used in the generation of the deviation in ewe weight at weaning, hereon referred to as DEVweanE.

Statistical Analyses

Genetic, permanent environmental, and residual components were estimated in Asreml (Gilmour et al., 2009) for each trait separately; the model employed was as follows:

$$Y_{ijklmngps} = \mu + CG_i + \text{Parity}_j * \text{AFL}_k + \sum_{(l=1)}^{5} \beta_l \text{Breed}_l + \text{Het}_m + \text{Rec}_n + \text{Ewe}_g + \text{EwePE}_p + \text{ServiceSire}_s + \text{e}_{ijklmngps}$$

where $Y_{ijklmngps}$ = DEV40L; μ = the population mean; CG_i = the fixed effect of contemporary group (i = 1,…, 113) ; $Parity_j*AFL_k$ = the interaction between ewe parity (j = 1, 2, 3, 4, ≥5) and age at first lambing (k = 8 and 18 mo of age or ≥18 and 28 mo of age); $\sum_{l=1}^{5} \beta_l \text{Breed}_l$ is the separate regression coefficients on the breed proportion of each of the 5 breeds (Belclare, Charollais, Suffolk, Texel, and Vendeen); Het_m = the fixed effect of the heterosis coefficient of the litter (m = <10%, ≥10% to ≤99%, and 100%); Rec_n = the fixed effect of the recombination loss coefficient of the litter (n = <10% and ≥10% to 50%); Ewe_g = random ewe direct additive genetic effect (g = 4,072), $[N(0, A\sigma_g^2)]$; $EwePE_p$ = random ewe permanent environmental effect (p = 4,072), $[N(0, I\sigma_{Pe}^2)]$; $ServiceSire_s$ = random effect representing the service sire of the litter (s = 408), $[N(0, I\sigma_S^2)]$; and $e_{ijklmngps}$ = random residual term, $[N(0, I\sigma_e^2)]$. The pedigree of each ewe was traced back 4 generations, where available.

The genetic, permanent environmental, and residual components for DEVweanL, DEV40E, and DEVweanE were also estimated using the model outlined above except the dependent variable (DEV40L) was replaced individually for the 3 aforementioned traits.

Breeding values for all traits (i.e., DEV40L, DEV40E, DEVweanL, and DEVweanE) were estimated in Mix99 (Lidauer et al., 2015) using the statistical models already described and the resulting variance components; in the genetic evaluation process, however, breed groups were fitted via the pedigree, and therefore, breed proportions were not included as fixed effects in the model.

RESULTS

Deviation in Litter Weight

The average litter weight at 40 d and weaning was 30.97 and 47.68 kg, respectively; the proportion of 40-d weight records in the edited dataset from single, twin, and triplet litters were 43%, 54%, and 3%, respectively. The proportion of phenotypic variation in 40-d litter weight explained by contemporary group, ewe weight, and litter age combined was 42%. The phenotypic SD in DEV40L was 8.46 kg, which represents 27% of the mean 40-d litter weight and 13% of the mean 40-d ewe weight. The regression coefficient of total litter weight at 40 d on ewe weight was 0.11 ± 0.01 kg; the regression coefficients of total litter weight at 40 d on lamb age were 0.27 ± 0.01, 0.44 ± 0.01, and 0.60 ± 0.05 kg for singles, twins, and triplets, respectively. The proportion of phenotypic variation in litter weight at weaning accounted for by the model that included contemporary group, ewe litter weight, and age of the litter was 41%. The phenotypic SD in DEVweanL was 15.37 kg, representing 32% of the mean litter weight at weaning and 23% of the mean ewe weight at weaning. The regression coefficient of total weaning weight on ewe weight was 0.14 ± 0.01 kg. The phenotypic correlation estimated between DEV40L and DEVweanL (n = 2,189 observations) was 0.90.

The heaviest DEV40L and DEVweanL were recorded in fourth parity ewes at 8.80 ± 0.89 and 20.05 ± 1.52 kg, respectively (Fig. 1). No difference in DEV40L and DEVweanL was observed for ewes lambing for the first time at either 8 or 18 mo of age

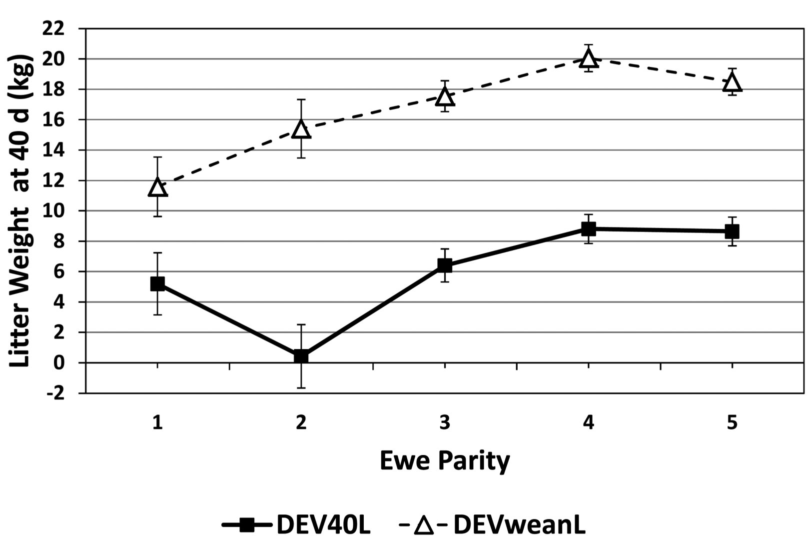

Figure 1. Mean litter weight (kilogram) by ewe parity (SE included in error bars) estimated for the deviation in 40-d litter trait (DEV40L; -■-) and for the deviation in weaning weight litter trait (DEVweanL; -Δ-).

or ≥18 and 28 mo of age. An interaction between ewe parity and age at first lambing was detected for DEV40L and DEVweanL ($P < 0.01$), with greater litter weight differences detected between age at first lambing in earlier parities, but this difference in litter weight diminished as parity number increased. Irrespective of the weight trait under investigation, litters with a greater proportion of the Belclare breed were consistently heavier than litters from all other breeds. Each 10% increase in Belclare proportion of the litter was associated with an increase in DEV40L of 0.21 kg (SE = 0.09). However, when DEV40L and DEVweanL were adjusted to a common litter size, each 10% increase in Suffolk and Texel proportion was associated with heavier DEV40L and DEVweanL compared with an increase in Belclare proportion. Irrespective of the trait under investigation, the deviation in litter weight increased as recombination class increased although the difference was not always significant; litters with a recombination loss of between ≥10% and 50% were 3.10 kg (SE = 0.80) and 2.99 kg (SE = 1.77) heavier at DEV40L and DEVweanL, respectively, compared with litter with a recombination loss of <10%.

The genetic SD and heritability for DEV40L was 2.65 kg and 0.12 (SE = 0.03), respectively. For DEVweanL, the genetic SD and heritability were 4.94 kg and 0.13 (SE = 0.04), respectively. The coefficient of genetic variation calculated for DEV40L and DEVweanL ranged from 9% to 10%; the mean respective litter weight was used as the denominator. The estimated dam permanent environmental repeatability was small in all traits (0.13 to 0.17).

The distribution of DEV40L and DEVweanL EBVs for purebred animals of the 5 main breeds is in Fig. 2. The mean DEV40L EBV for animals with an accuracy of >0.20 for purebred Belclare

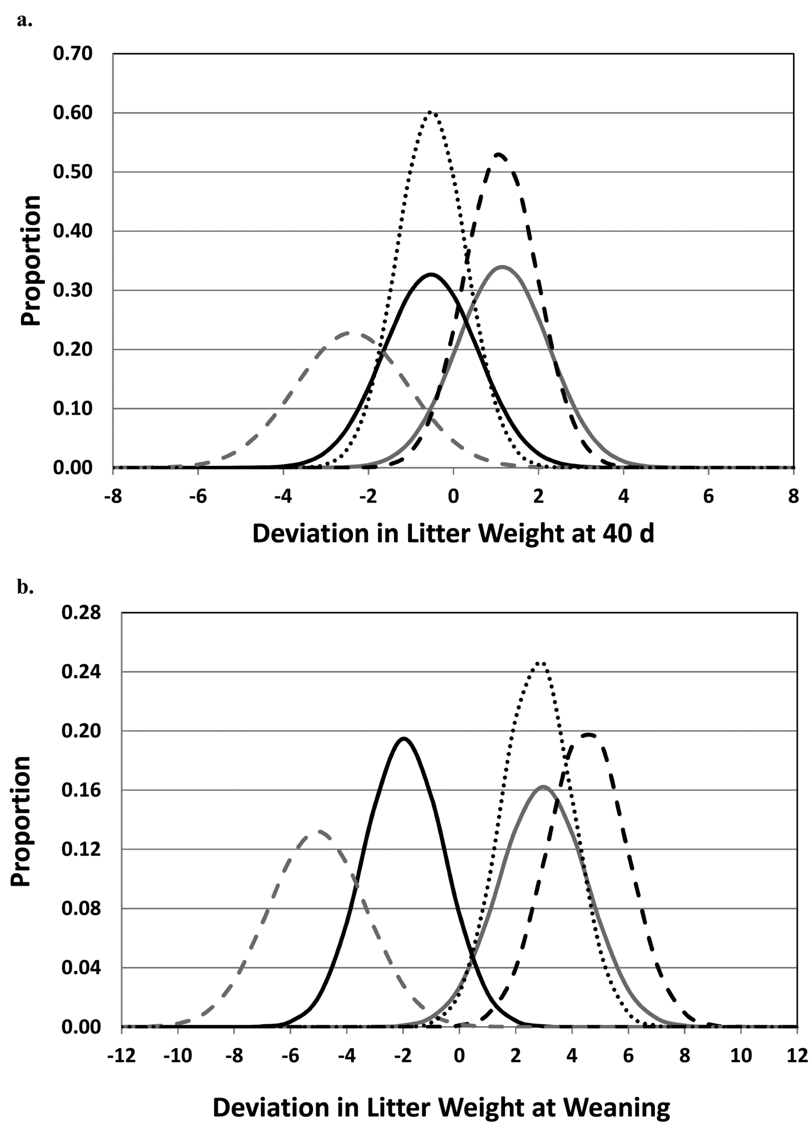

Figure 2. Distribution of EBVs for deviation in litter weight at 40 d (a) and weaning (b) for purebred Belclare (continuous gray line), Charollais (dashed black line), Texel (black line), Suffolk (dashed gray line), and Vendeen (dotted black line).

(n = 155), Charollais (n = 18), Texel (n = 95), Suffolk (n = 53), and Vendeen (n = 21) was 1.16, 1.11, −0.53, −2.38, and −0.52 kg, respectively. The average within breed correlation between DEV40L EBV and DEVweanL EBV ranged from 0.65 (Vendeen breed) to 0.75 (Belclare breed).

Deviation in Ewe Weight

The average ewe weight at 40-d postlambing and at weaning was 66.43 and 66.87 kg, respectively. The proportion of variation in ewe weight at 40-d postlambing explained by litter weight, contemporary group, and days postlambing was 53%; the corresponding value for ewe weight at weaning was 70%. The phenotypic SD in DEV40E and DEVweanE was 11.27 and 13.68 kg, respectively, which represents 17% and 20% of the average ewe weight at 40-d postlambing and weaning, respectively. The regression coefficient of ewe weight at 40 d on total litter weight at 40 d was 0.53 ± 0.03 kg; the corresponding the regression coefficients of ewe weight at weaning on total litter weaning weight was 0.23 ± 0.02 kg. The phenotypic correlation between DEV40E and DEVweanE (n = 2,189 ewes) was 0.85.

Relative to first parity ewes, fifth parity ewes were on average 8.12 kg (SE = 2.17) heavier at DEV40E. Ewes that lambed for the first time as hoggets (i.e., ≥18 and 28 mo of age) were on average 1.53 kg (SE = 0.82) and 1.36 kg (SE = 0.84) heavier at DEV40E and DEVweanE, respectively, compared with ewes that lambed for the first time as ewe lambs (i.e., 8 to 18 mo of age). Each 10% increase in Suffolk proportion was associated with an increase in DEV40E of 0.20 kg (SE = 0.12).

The coefficient of genetic variation for DEV40E was 7%. The genetic SD and heritability for DEV40E was 4.33 kg and 0.24 (SE 0.04) (Table 1), respectively. The ewe repeatability was 0.45 (SE 0.03). The genetic SD and heritability estimated for DEVweanE was 4.77 kg and 0.31 (SE 0.04), respectively. A large dam repeatability was estimated for DEVweanE (0.56; SE 0.02) (Table 1).

Figure 3 shows the distribution in EBVs for DEV40E and DEVweanE for purebred animals of the 5 main breeds. The mean DEVweanE EBV for purebred animals with an accuracy of >0.20 for Belclare (n = 382), Charollais (n = 97), Texel (n = 230), Suffolk (n = 143), and Vendeen (n = 49) was 1.10, −1.39, 1.11, 3.93, and −7.89 kg, respectively. The average within breed correlation between DEV40E EBV and DEVweanE EBV ranged from 0.47 (Suffolk breed) to 0.78 (Texel breed).

DISCUSSION

The growing demand for animal-derived energy and protein sources by the expanding and more affluent human population necessitates evaluating alternative strategies to increasing sustainable productivity and efficiency in all livestock species, including sheep. Many studies attempt to address this global challenge by focusing on the mature animals, and in particular the size (as a proxy for feed intake) of the mature herd, as a strategy to minimize not only the environmental footprint but also the cost of production of the entire sector. The genetic correlation between mature weight and weight in younger animals is generally positive (0.16 to 1.00) across species including in cattle (0.16 to 1.00; Koenen and Veerkamp, 1998; McHugh et al., 2011) and sheep (0.19 to 0.93; Safari et al., 2005). This therefore implies that direct selection for reduced mature size will, on average, reduce the size of offspring, which may have repercussions for the efficiency of the entire sector. However, because the genetic correlation between weight in mature and younger animals is (mostly) less than unity, then concurrent genetic selection for lighter mature animals but heavier younger animals destined for slaughter is indeed possible. The potential may actually be greater in pluriparous species such as sheep where one objective may be to increase the total weight of the litter without necessarily increasing or indeed even reducing the weight of the mature female. This hypothesis was examined in the present study, mainly through the quantification of the phenotypic and genetic variability in

Table 1. Number of litters or ewes (n), mean weight (μWT), genetic SD in kg (σ_g), direct heritability (h^2_d; SE in parentheses), and maternal repeatability (t_{dam}) for litter and ewe weight at 40 d and weaning

Trait	n	μWT	σ_g	h^2_d	t_{dam}
Litter weight 40 d (kg)	4,838	30.97	2.65	0.12 (0.03)	0.13 (0.04)
Litter weaning weight (kg)	4,817	47.68	4.94	0.13 (0.04)	0.17 (0.04)
Ewe weight 40 d (kg)	4,838	66.43	4.33	0.24 (0.04)	0.45 (0.03)
Ewe weaning weight (kg)	4,817	66.87	4.77	0.31 (0.04)	0.56 (0.02)

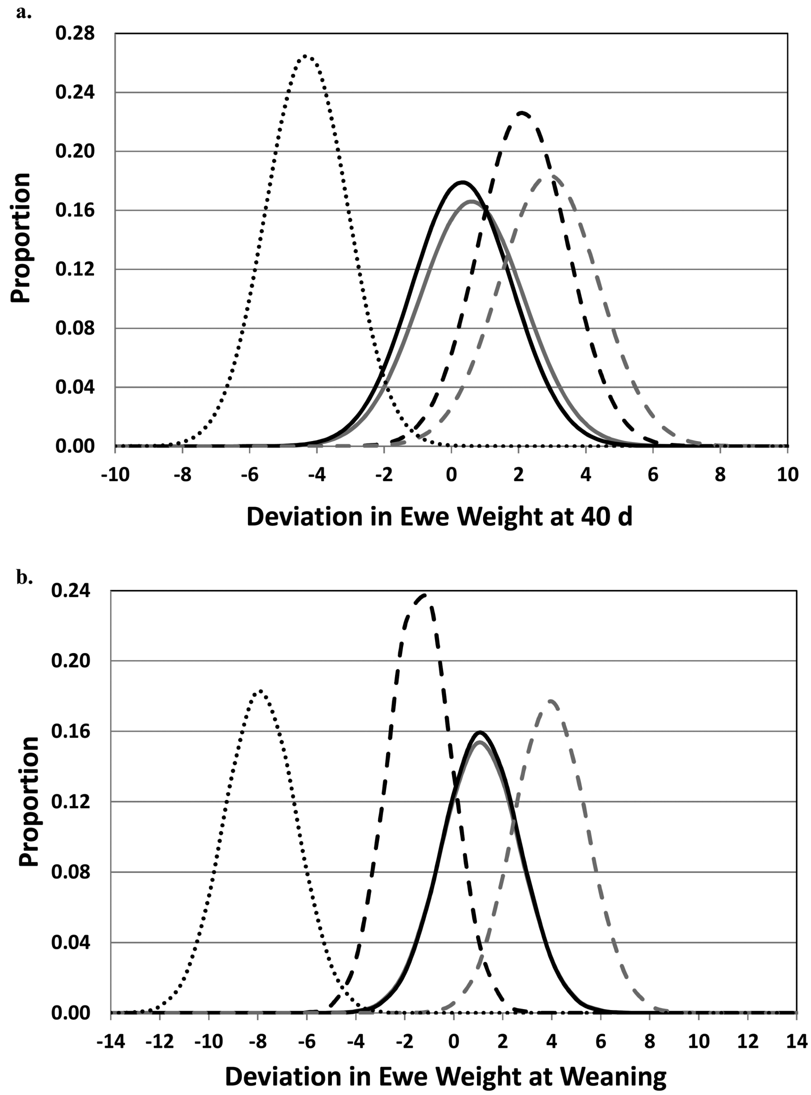

Figure 3. Distribution of EBVs for deviation in ewe weight measured at 40-d postlambing (a) and at weaning (b) for purebred Belclare (continuous gray line), Charollais (dashed black line), Texel (black line), Suffolk (dashed gray line), and Vendeen (dotted black line).

total litter weight relative to that of the ewe, and vice versa. Results from the present study clearly indicate considerable variability in litter weight relative to a common ewe weight (and vice versa) both of which are up to 31% heritable with a coefficient of genetic variation of up to 10%. In addition, the formation of the new trait of litter weight relative to a common ewe weight provides a novel phenotype for phenotypic benchmarking purposes, in that ewes can be ranked within flock on their phenotypic efficiency but also flocks can be ranked against each other on overall ewe phenotypic efficiency performance.

Usefulness of the Novel Measures in Breeding Programs

Discussions on efficiency in livestock generally focus on (daily) feed intake and (daily) net feed efficiency (Koch et al., 1963; Berry and Crowley, 2013). Efficiency at the system level consists of more than simply feed intake but instead is affected by factors such as litter size, animal mortality, and ewe longevity (Lee et al., 2015; McHugh et al., 2016; Earle et al., 2017). Although direct selection on net feed efficiency requires animal-level information on feed intake, phenotypic data on litter size, mortality, and ewe longevity are often readily available in sufficient numbers to achieve high accuracy of selection. Moreover, the relatively high heritability of the traits investigated in the present study implies only few records are required to achieve a high accuracy of selection; this is especially true for the ewes themselves in that the accuracy of mass selection is also relatively high. The heritability of DEV40E and DEVweanE of between 0.24 and 0.31 is similar to reported for mature ewe weight both in Irish sheep populations (0.37; McHugh and

Pabiou, 2014) and elsewhere (0.25 to 0.41; Fogarty, 1995; Safari et al., 2005; Lobo et al., 2012). The lower heritability of the deviation traits at the level of the litter (i.e., DEV40L and DEVweanL) relative to that at the level of the ewe (DEV40E and DEVweanE) is not unexpected since the former includes some element of litter size, which is known to be lowly heritable in many sheep breeds (Rosati et al., 2002; Cloete et al., 2004; Safari et al., 2005); in fact, based on a statistical model regressing DEVweanL on both litter size and average lamb weight in the litter, 80% of the phenotypic variability in DEVweanL was attributable to litter size, with an additional 13% attributable to average lamb weight in the litter.

Heritability estimates are often cited in genetic studies, yet when determining the potential response to selection, arguably the extent of genetic variation in a given trait is of greater importance (Houle, 1992). The genetic SD of 4.94 kg in the present study for deviation in litter weaning weight indeed suggests considerable scope exists to alter the trait. Similarly, a large genetic SD for deviation in ewe mature weight recorded at 40 d or weaning (4.33 to 4.75 kg) also indicates potential to genetically select more efficient animals. The coefficient of genetic variation for the traits measured in the present study (7% to 10%) are similar to those previously reported for lamb (15% to 18%) and ewe (6% to 12%) weight traits (Safari et al., 2005) and indeed for milk yield in dairy cattle (6%; Berry et al., 2003). Given the large increases in genetic gain that have been achieved for milk yield in dairy cattle (Hansen, 2000), this therefore suggests that in a well-designed breeding program there is potential to increase the rate of genetic gain for sheep efficiency traits.

Usefulness of the Novel Measures in Benchmarking Strategy

Agriculture in general is undergoing a “datafication” revolution with ever-increasing quantities of data being generated; the sheep sector is not exempt from this revolution. The challenge becomes how these data can be converted into easily understandable, useful benchmarking statistics for producers, not only for identifying ewes within a flock for culling, but also for benchmarking flocks against each other. Although the contribution of genetic gain of the dams-to-dam pathway is small relative to the other 3 selection pathways (predominantly because of the relative differences in selection intensity applied), merit still exists in the culling of the ewes expected to have the least contribution to the future profitability of the flock. Kelleher et al. (2015) developed an index for dairy cows to quantify the profit expected to be generated by each cow for the remainder of her lifetime and illustrated how such an index can contribute to increasing the profit for a herd. The efficiency traits developed in the present study could form a valuable component in such an index to rank ewes within flock on expected profit but also each ewe’s contribution to the total environmental intensity of the flock. Based on the observed phenotypic SD of 15.37 kg in the present study for DEVweanL, the expected difference between the top and the bottom 10% of litters ranked on DEVweanL, equates to nearly (i.e., 98%) the mean litter weight at weaning in the entire dataset. Similarly, the phenotypic SD for deviation for ewe weaning weight (13.68 kg) indicates that the expected differences between the top and bottom 10% of ewes ranked on DEVweanE equate to 72% of the mean ewe weaning weight. The desire to improve (flock) performance is undoubtedly related to how the flock compares with contemporaries and thus the capacity for improvement. Such comparisons could be at the level of the flock revenue, costs of production, or profit, but could also be undertaken at the individual trait (or index) level. Given that lamb (carcass) weight is the main contributor to flock revenue, and the maintenance of the mature flock (approximated from the weight of the ewes) is the main contributor to the costs of production (Bohan et al., 2016), an index that combines both elements could be useful for evaluating flock performance and benchmarking against contemporaries. Moreover, the flock best linear unbiased estimates (BLUE) solutions from the genetic evaluation could be used to more objectively compare flocks after accounting for differences in mean random (genetic) effects of the flock and contributing fixed effects. The comparison of flock BLUEs and best linear unbiased predictions can be used in tailoring the advice given to producers on how to improve performance. Moreover, the resulting model solutions for the fixed effects estimated in the present study can also aid in providing advice on how performance can be improved. For example, the analysis from the present study clearly highlighted that number of lambs born as well as ewe parity and breed were all associated with the traits investigated in the present study. Results from the present study show that 80% of the phenotypic variability in DEVweanL could be explained by litter size alone, thus substantiating the findings of Earle et al. (2017) who have shown that number of lambs weaned per ewe, rather than the weight of individual lambs, is of key importance to sheep systems.

In conclusion, considerable phenotypic and genetic variation exists for the 4 novel phenotypes defined in the present study. The phenotypic information required to derive these phenotypes is routinely available, which enables 1) exploitation through breeding programs and 2) routine benchmarking both within and between flocks. Although the approaches adopted in the present study to generate the deviation traits were based on phenotypic regressions, it is also possible to use genetic regressions thereby ensuring genetic independence between litter weight and ewe weight; such a strategy has been discussed in detail for residual feed intake (Kennedy et al., 1993).

LITERATURE CITED

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