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Estimation of genetic parameters for reproductive indices in sheep

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Abstract

This study aimed to estimate two reproductive efficiency indices in sheep based on the ratio between litter weight (at birth and weaning) and dam weight, as well as their genetic parameters. Phenotypic and pedigree data comprising the period from 1990 to 2018 were obtained from the Santa Inês sheep database of Embrapa Tabuleiros Costeiros. For estimation of the genetic parameters of the indices, a repeatability model was applied in single- and two-trait analyses by a Bayesian approach. The mean reproductive efficiency index was 0.069 ± 0.0163 and 0.43 ± 0.0955 at birth and weaning, respectively. These values indicate that, on average, ewes give birth to 69 g of lamb per kg body weight and wean 430 g of lamb per kg body weight. Described here for the first time, the heritability estimate obtained in single- and two-trait analyses was 0.24 for the index based on birth weights and ranged from 0.13 to 0.15 for the index based on weaning weights. The estimates indicate the possibility of genetic gain by selection and are similar to those reported for reproductive traits in sheep, representing an option for selection criterion. The genetic correlation between indices was positive and moderate (0.26). The repeatability estimates were high (0.49 for the birth weight index and 0.71 for the weaning weight index). These values indicate good prediction of future performance with few observations. The weaning weight index might be a good culling criterion of females.

KEYWORDS

culling, dam weight, litter weight, reproduction, selection

1 | INTRODUCTION

The reproductive and productive performance, rusticity and good adaptation to different systems and edaphoclimatic conditions have rendered Santa Inês sheep as one of the most popular breeds in Brazil. This breed is widely distributed in the country, with the largest number of flocks (>3300) and the presence of herds throughout the national territory (>1300 municipalities) (McManus et al., 2014). This popularity is due to the challenging adaptation of European breeds to the tropical climate. Since Santa Inês sheep is adapted to hot climate, it is a viable alternative in tropical regions and widely raised.

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In general, growth and weight traits in sheep have medium heritabilities (Aguirre et al., 2016; Medrado et al., 2021; Oliveira et al., 2021), while reproductive traits have low heritabilities (Jafaroghli et al., 2022; Medrado et al., 2021; Quesada et al., 2002). Although it is difficult to obtain genetic gain for reproductive traits, they are among the economic importance traits in sheep production (McManus et al., 2011).

Pettigrew et al. (2018) developed an index to measure the reproductive efficiency of sheep. This index is obtained by dividing the litter weight at weaning by the pre-breeding weight of the ewe. The results showed that the most efficient females are those born to young dams and from twin births. The proposed index may be an alternative tool for the reproductive evaluation and selection of animals in the herd since it estimates the efficiency of females based on a body weight ratio. Traits that are based on the progeny weight such as accumulated productivity, the ratio of calf weaning weight on dam weight, are used in cattle to evaluate dam reproductive efficiency (Schmidt et al., 2018). It measures the female capacity to start reproductive life as well as the ability to remain in the herd and it is more heritable than other reproductive traits (Schmidt et al., 2018). In sheep, total litter weaning weight is also used to evaluate reproductive efficiency; however, the heritability estimates are low (Baneh & Ahmadpanah, 2020; Baneh et al., 2020; Boareki et al., 2021; Haile et al., 2019; Jafaroghli et al., 2022). A ratio of lamb weight and ewe metabolic weight (Lôbo et al., 2012) and combined index of lamb and ewe weight were also proposed to assess ewe efficiency (McHugh et al., 2018), having heritability estimates of low and low to moderate, respectively.

Therefore, the aim of the present study was to evaluate the reproductive efficiency of Santa Inês sheep using indices of the ratio between litter weight and dam weight and to estimate their genetic parameters.

2 | MATERIALS AND METHODS

Ethics Committee approval for use of the animals was not necessary since the information used was extracted from an existing recording database. Phenotypic and pedigree data were obtained from the database of Santa Inês Conservation Center at Embrapa Tabuleiros Costeiros. The animals were born and raised between 1990 and 2018 in Campo Experimental Pedro Arle, Frei Paulo-SE, Brazil.

The animals were reared in a semi-intensive system, with ad libitum supply of mineral salt and water. The reproductive cycle was carried out every 12 months, with parturitions occurring during the rainy months (from May to October). Rare exceptions occurred during the dry period (from November to April). Data on productive management were collected and controlled regularly, as were pedigree data. Weights, dates and animal identification were recorded at different stages of life, such as lambing and weaning.

The records of animals were entered into a single database using the R software in order to clean inconsistencies. The parity order was determined based on the parity sequences of ewes. The database contained information on 4383 ewes and there were 6379 animals in the pedigree and three generations.

The individual reproductive efficiency (REi) of females was evaluated using an adaptation of the index proposed by Pettigrew et al. (2018) estimated at the birth (REib) and weaning (REiw) stage. It is a trait of the dam. The index was calculated by dividing total litter birth weight (BWt) or lamb weaning weight (WWt) by dam live weight after lambing (LWd) as follows:

$$\text{REib} = \frac{\text{BWt(kg)}}{\text{LWd (kg)}} \text{ or Eiw} = \frac{\text{WWt (kg)}}{\text{LWd (kg)}},$$

The number records were 4071 (BWt) and 3142 (WWt). The covariance components were estimated using the BLUPF90 family (Misztal et al., 2014) of programs under Bayesian approaches (GIBBS2F90) and convergence of the Gibbs posterior chains was analysed using POSTGIBBSF90. A total of 3,000,000 Gibbs samples and a burn-in of 300,000 samples were used to estimate the variance components, with a thinning interval of 50. Convergence was checked by applying the Z criterion of Geweke (1991).

The genetic parameter estimates were obtained using a single- or two-trait repeatability model. The model can be written as follows:

$$\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{Zu} + \boldsymbol{Wpe} + \boldsymbol{e},$$

where $\boldsymbol{y}$ is the vector of observations of the traits, $\boldsymbol{X}$ is the incidence matrix of fixed effects, $\boldsymbol{\beta}$ is the vector of fixed effects, $\boldsymbol{Z}$ is the incidence matrix of direct genetic effects, $\boldsymbol{u}$ is the vector of random direct genetic effects, $\boldsymbol{e}$ is the vector of residual effects, $\boldsymbol{pe}$ is the vector of permanent environmental effects and $\boldsymbol{W}$ is the incidence matrix of permanent environmental effects. The fixed effects included lamb gender, birth status (singleton or multiple) and parity of the dam (first, second or + third parity), year of birth of the lamb, birth status (singleton or multiple) and parity of the dam (first, second or + third parity) from which the ewe was born, as well as age of lamb as covariate (just for REiw). The values of the indices were multiplied by 100

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for genetic parameter analysis. If a lamb did not have its weaning weight recorded, it was estimated using the following formula:

$$WWe = \{[(BW - BWm)/100] \times WWm\} + WWm,$$

where WWe is the predicted weaning weight of the lamb, BW is the birth weight of the lamb, BWm is the mean birth weight of the lamb/female and WWm is the mean weaning weight of the lamb/female.

For comparison, the genetic parameters for Total Litter Weight at Weaning (TLWW), another reproductive trait, was also estimated. The single- (TLWW) and two-trait (TLWW and REiw) repeatability model was applied using REiw effects.

3 | RESULTS

The descriptive statistics for the studied reproductive efficiency indices are presented in Table 1. The results showed that, on average, ewes give birth to 69.5 g of lamb per kg body weight and wean 432.1 g of lamb per kg body weight.

The (co)variance components and genetic parameter estimates based on the single-trait models are presented in Table 2. The heritability estimates were of low-to-moderate magnitude, while the repeatability coefficients were high.

The (co)variance components and genetic parameter estimates based on the two trait models are presented in Table 3. The heritability coefficients estimated for REib and REiw were also of low-to-moderate magnitude and were slightly higher than those obtained with the single-trait model. The repeatability estimates continued to be high. The genetic correlation between indices was positive and moderate.

For birth index (REib), all the examined fixed effects were significant ($p < 0.05$). For weaning index (REiw), the effects were also significant, except for the birth status of ewe ($p = 0.0333$). However, it is associated with the parity of the dam, so it was included in the model for adjustment. The age of lamb at weaning used as covariant and also was significant ($p < 0.0001$).

The genetic parameters for total litter weight at weaning (TLWW) are presented in single- (Table S1) and two-trait analyses (TLWW and REiw) (Table S2).

4 | DISCUSSION

The mean individual reproductive index based on the weights of lambs at weaning (REiw) is 0.432. This value is lower than 0.78, reported for wool sheep in New Zealand (Pettigrew et al., 2018). This result suggests that sheep raised in New Zealand might be superior in terms of reproductive efficiency. This large difference can be explained not only by the fact that the herd has been submitted to genetic selection for decades but also due to the differences in the rearing system, climate, nutritional quality of pastures, breed and dam weight used in the calculation. The values of the individual reproductive efficiency index based on birth weights (REib) are the first reported in the literature.

Genetic parameter estimation revealed heritability values of the individual female reproductive efficiency indices, REib and REiw, ranging from 0.13 to 0.24. These values are a bit higher than the ones reported by Lôbo et al. (2012) that estimated heritability for a similar trait (the ratio calculated by Lôbo et al., 2012 considered ewe metabolic weight instead of ewe body weight in denominator). The REib and REiw heritability values are similar to the ones reported for TLWW (Tables S1 and S2). It indicates a similar chance of genetic gain under selection, being an option criterion to select for reproductive performance in sheep. By measuring reproductive efficiency using a weight ratio, the heritability estimates are similar to the heritabilities for weight traits in sheep (Aguirre et al., 2016; Medrado et al., 2021; Oliveira et al., 2021), so the genetic gain could be higher. In beef cattle, reproductive indices assessing weights such as accumulated productivity, defined as the amount of weaned calf per cow per unit of time has been suggested to be used to select more fertile and long-lived dams and heavier calf at the weaning stage (Grossi et al., 2016; Schmidt et al., 2018).

The genetic correlation between indices was ~0.27, indicating that a certain gain can be obtained in one index if the other were selected. However, traits at weaning tend to have higher economic values (McManus et al., 2011). Among the studied traits, the TLWW and REiw are heritable and can be used in genetic selection program with a genetic correlation of ~0.55 between traits.

The repeatability estimates of REib (0.49) and REiw (0.71) are high, indicating major contribution of genotype

TABLE 1 Descriptive statistics for the reproductive efficiency indices of lamb weight at birth (*REi*b) and at weaning (*REi*w) in Santa Inês sheep.

Trait	*N*	Mean	SD	SEM	CV (%)	Minimum	Maximum
REib	4071	0.0695	0.0163	0.0003	22.70	0.0165	0.1432
REiw	3142	0.4321	0.0955	0.0017	22.11	0.1228	0.8404

Abbreviations: CV, coefficient of variation; *N*, number of animals; SD, standard deviation; SEM, standard error of the mean.

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TABLE 2 The (co)variance components and genetic parameters for the reproductive efficiency indices of lamb weight at birth (*REi*b) and at weaning (*REi*w) estimated using single-trait analysis in Santa Inês sheep.

Trait	σ^2_a	σ^2_{pe}	σ^2_e	*R*	h^2
REib	0.0000449 (0.0000290–0.0000629)	0.0000465 (0.0000326–0.0000605)	0.0000928 (0.0000888–0.0000973)	0.4959 (0.4586–0.5332)	0.2430 (0.1552–0.3308)
REiw	0.001136 (0.0000534–0.002218)	0.004635 (0.003594–0.005676)	0.002350 (0.002218–0.002481)	0.7100 (0.6798–0.7403)	0.1389 (0.0119–0.2658)

Note: The confidence intervals are in parentheses.

Abbreviations: h^2, heritability; *r*, repeatability; σ^2_a, additive genetic variance; σ^2_e, residual variance; σ^2_{pe}, permanent environmental variance.

TABLE 3 The (co)variance components and genetic parameters for the reproductive efficiency indices of lamb weight at birth (REib) and at weaning (REiw) estimated using two-trait analysis in Santa Inês sheep.

Trait	σ^2_a	σ^2_{pe}	σ^2_e	*r*	h^2	rg	Re	rp
REib	0.0000458 (0.00002739–0.00006428)	0.00004646 (0.00003227–0.00006066)	0.00009269 (0.00008815–0.00009723)	0.4984 (0.4609–0.5359)	0.2460 (0.1576–0.3363)	0.2679 (−0.2006–0.7365)	0.2070 (0.1699–0.2440)	0.2259 (0.0806–0.3713)
REiw	0.001306 (0.000213–0.002398)	0.004588 (0.003551–0.005625)	0.0023533 (0.002222–0.002484)	0.7140 (0.6834–0.7446)	0.1573 (0.0323–0.2823)			

Note: The confidence intervals are in parentheses.

Abbreviations: h^2, heritability; *r*, repeatability; re, residual correlation; rg, genetic correlation; rp, phenotypic correlation; σ^2_a, additive genetic variance; σ^2_e, residual variance; σ^2_{pe}, permanent environmental variance.

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and permanent environment to the expression of the traits. The studied indices, especially for REiw, can be used to estimate the future performance of ewe using few observations with enough accuracy.

5 | CONCLUSION

In this study, two reproductive efficiency indices of lamb weight at birth (REib) and at weaning (REiw) were defined for Santa Inês sheep. The results showed that the suggested indices are heritable and have the potential to be used in genetic selection. The repeatability estimates indicate good prediction of future performance with few observations, being a good criterion to cull females and improve reproductive performance of the herd. Future studies that include mortality rates combined with calculation of the index and that estimate correlations with other reproductive traits may greatly contribute to the definition of selection and replacement objectives in sheep.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from Hymerson Costa Azevedo (hymerson.azevedo@embrapa.br). The data are not publicly available due to privacy.

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