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Genetic analysis of age at conception as a fertility proxy in ewe lambs of Norwegian White Sheep: heritability and genetic correlation with body growth and leanness

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Erasmus Master's in Animal breeding and genetics

Preface

This master's thesis marks the end of my Master's degree in Animal Sciences with the specialization in Animal Breeding and Genetics at the Norwegian University of Life Sciences (NMBU), Department of Animal and Aquacultural sciences (IHA). Several people deserve credit for helping me complete this thesis. Firstly, I would like to thank my supervisors Prof. Geir Steinheim and Gunnar Klemetsdal at NMBU for his guidance, good discussions, and encouragement throughout the process of writing this thesis. I want to thank The Norwegian Association of Sheep and Goat Farmers (NSG) for providing the data material, and for answering my questions. I would also thank my co-supervisor Prof. Bart Ducro, Wageningen University and research for the useful comments, quick responses, and support. A special thank goes to Célian Diblasi for supporting me and for spending hours reading through my writing.

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Abstract

The aim of this study was to estimate the genetic variation and heritability of ewe's age at first lambing (a fertility proxy) in ewe lambs of Norwegian White Sheep and to estimate the genetic correlations between number of days till lambing and, respectively, growth rate and fat deposition at slaughter (EUROP classification score) in half year-old ewes, utilizing data on the ewe itself or on sibs (for fat deposition). The data of this study is from the breed Norwegian white sheep (NWS) and was made available by Animalia. From the original dataset one dataset was sampled containing 91683 females with weaning weight information and amongst these 31002 ewes with information for number of days at lambing. Pedigree files traced back to third generation were used in the analysis. Age at litter, the fertility success trait showed considerable heritability of 0.08 and had a genetic and environmental correlation of zero with the most focused traits in the Norwegian sheep breeding program; growth rate and fat score. Therefore, we conclude that farmers can select this fertility success trait without affecting the current objectives of the breeding goal. On the contrary, such a strategy would make positive steps towards economic and environmental sustainability.

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1 Introduction

The sheep industry in Norway significantly contributes to the agricultural income of the country along with contributing to maintenance of the rural population. Norway produces the highest sheep meat in Scandinavian countries with almost 1.3 million lambs and sheep slaughtered in 2017. Over the last few years, between 2012 and 2017, sheep meat production has increased by 8.4% (Bhatti et al., 2019) . Farmers have, in main, selected animals for high growth rate, high meat percentage and low-fat content as per the consumer and economic demand. The breeding values for these traits have been combined into an index, gradually being developed after the first progeny testing of rambs was carried out in 1965 (Eikje, 1975).

In order to increase farmers' income and viability in the sheep sector, animals need to become more productive (Abegaz et al., 2010). The reproductive rate determines the number of lambs born affecting profitability of the sheep flock. Higher reproduction also provides more opportunity to control the inbreeding rate (Rash & lmou, 1994). Reproduction success depends on easiness to conceive and the ability to sustain pregnancy. Reproduction and the reproductive rate have been shown to be markedly influenced by genetic, physiological, and environmental conditions at mating(Kenyon et al., 2014). Along with parity, dam weight, dam age, and lambing season other non-genetic factors like variation in photoperiods that control melatonin secretion can have an influence on reproductive success traits. (Joshi et al., 2018)demonstrated that the productive and reproductive traits vary with age of conception, lambing interval, and litter size. Age and weight at first mating are considered critical factors for increased litter size in ewes (Lee et al., 2019). Breeders commonly use the age of ewes at first mating as a measure of dam reproductive performance (Koketsu et al., 2020).

Sheep reproductive traits such as age at first lambing, litter size, and lambing interval have high economic value in all sheep production systems (Yavarifard et al., 2015) . Traditionally, among fertility traits, only number of lambs born has been given economic weights in Norwegian sheep breeding (Lillehammer et al., 2020), while success traits have not been genetically analyzed. In pasture-based production systems, the overall production efficiency depends heavily on the maternal abilities of ewes. Since the Norwegian white sheep breeding program has experienced a large genetic gain for the litter size, there is a demand for ewes that can feed and raise multiple lambs (Lillehammer et al., 2020). So, it is very important to consider these maternal success traits in the breeding goal along with other production traits. Even though Artificial Insemination has been practiced since 1975, according to the Norwegian sheep breeding council, the farmers have recently experienced problems with fertility in around 16.5% of young ewes. Fertility levels in ewes have been declining, particularly in Norwegian white sheep (Holmøy et al., 2014). Recently, the global sheep industry has come under pressure because of an increasing concern about methane emissions. Sheep that are not reproducing are only producing methane, so there is a renewed focus on the reproductive efficiency of individual ewes, as well as the whole flock, as a pathway to the reduction in 'emissions intensity' (units of methane per unit of product) all over the world. We need to produce more lambs and produce them faster. The focal points are ovulation rate (number of eggs released by an animal that ovulates), fertility at mating, embryo mortality, postnatal mortality, and delayed puberty (Rosales Nieto et al., 2018). Including fertility as part of a selection index for total profit can halt the downward genetic trend and assist in achieving compact breeding pattern. However, there are major challenges for achieving a favorable genetic gain in fertility: (1) a lack of good quality data, (2) definition of the selection objective trait; and (3) inadequate selection pressure on fertility traits within a multi trait selection index.

The timing of puberty onset has a great influence on animal productivity. Previous studies show that puberty, that is defined as the first spontaneous ovulation is initiated when an individual exceeds a critical body size during development (Nieto et al., 2013) and when photoperiod becomes permissive (Decourt & Beltramo, 2018).When body weight was below that threshold, the first ovulation in Mouflon and Manchega ewe lambs did not occur until the beginning of the next breeding season (Santiago Moreno et al., 2000). The descriptive statistics by the Norwegian sheep breeding council also suggest that the ewe body weight at weaning is important for successful reproduction of ewes. If growth during early life is restricted, young ewes will remain pre-pubertal until the required proportion of mature body mass is reached hence, rapidly growing lambs achieve puberty earlier than slower growing lambs (Nieto et al., 2013). This implies that number of days till mating will be longer for the latter, and from this one can expect not only negative phenotypic but also negative genetic and environmental correlations between these two traits.

However, neither mating dates nor weight at mating are recorded in Norwegian sheep recording (NSR), Proxies are however available, as age in number of days till first lambing (assuming no variance in gestation length between individuals), as the measure of age at successful mating, and the lamb's growth rate till autumn weighting (weighted at somewhat different ages, though). With selection for an increased growth rate, also the adult weight is expected to increase (Nieto et al., 2013), meaning that the animal might be physiologically younger at mating. (Alkass et al., 1994)showed that ewes that grew faster reached puberty at a younger age. This is expected to modify the genetic correlation pattern in direction of a positive genetic correlation, meaning that animals growing genetically well is expected to be successfully mated later. The joint effect of these variables can be estimated by the genetic correlation between the ewe growth rate and number of days till lambing, the latter being assumed as one fertility success trait.

The impaired fertility in the half year old ewes can possibly also be related the available fat reserves. According to (Frisch, 1984), studies in humans have shown that during sexual maturation or puberty, the body require a lot of calories and these calories are mainly stored as fat reserves. Age and weight have long been considered the dominant factors that influence the onset of puberty and, for many years, it has been accepted that these relationships are mediated by the hormone, leptin, produced by body fat (Rosales Nieto et al., 2018). Another finding about body fat during the adolescent spurt is of special interest: Fat increases linearly with increasing lean body weight for all subjects at menarche and at spurt initiation, but at both events fat increases at a slower rate with increasing lean body weight in late maturers than in early maturers, meaning that late maturing girls had less fat on the average at each event than did early maturers, although they did not differ in lean body weight. Since fat converts androgens to oestrogens, the relative degree of fatness is directly related to both the quantity of circulating oestrogen and its biological effectiveness, because body weight influences the metabolism of oestrogen to its most potent or least potent forms (Frisch, 1984). Therefore, higher fat score might correlate with higher reproductive success. Hence, selection against fat, which is currently preferred by the farmers and consumers in Norway, might influence fertility. Thus, the value of selecting for increased genetic merit in fat cannot be determined without exploring the genetic relationships with fertility in the breeding ewe., and we hypothesize that the two trait has a genetic correlation different from zero.

The aim of this study was to estimate the genetic variation and heritability of ewe's age at first lambing (a fertility proxy) in ewe lambs of Norwegian White Sheep. Another aim was to estimate the genetic correlations between number of days till lambing and, respectively, growth rate and fat deposition at slaughter (EUROP classification score) in half year-old ewes, utilizing data on the ewe itself or on sibs (for fat deposition).

2 Materials and Methods

2.1 Norwegian sheep breeding Scheme

The present breeding scheme for sheep in Norway was mainly established during the 1960s and was made operative through the breeding plan from 1968. In this breeding scheme, the ram lambs are selected based on phenotypics / appearance and pedigree (and index), and are later progeny tested in the ram circles. Out of these, the best performed ones are made as Elite rams which are mated to the best ewes in the circles. Later, the ones with the best progeny (and index) may be selected as AI rams. Ewes are selected according to a selection index (L. S. Eikje et al., 2008). The index calculations are based on genomic BLUP (Best Linear Unbiased Prediction), introduced in 2020. Lately, the use of artificial insemination (AI) has become more frequent, with about 30000 doses, mostly in the ram circles. The breeding organization "The Norwegian Association of Sheep and Goat Breeders" (NSG) decides the minimum score needed to be eligible for selection. The selection decision is then made by the farmers in the ram circle, among the eligible rams (Lillehammer et al., 2020). The conventional progeny testing scheme used in the present sheep breeding program is optimized to improve growth related traits. Implementation of genomic selection will help in improving genetic gain of maternal traits, i.e., traits that is recoded on the ewe, mastitis, lambing difficulties, fertility success traits, methane emission, adult ewe weight etc. The changes to the breeding scheme from genomic BLUP will also result in increased accuracy of ram at a young age, allowing to select elite rams earlier (both elite rams and AI rams) (Lillehammer et al., 2020).

2.2 Data

The data of this study is from the breed Norwegian white sheep (NWS) and was made available by Animalia. NWS accounts for 70% of the registered Norwegian sheep in Norway and is well known for its high growth rate and high prolific ability. From the original dataset one dataset was sampled containing 91683 females with weaning weight information and amongst these 31002 ewes with information for number of days at lambing. Pedigree files traced back to third generation were used in the analysis. We limited it to three due to limited computational resources. Data analyzed was from the farms in old Buskerud County. The NWS ewes that give birth one year old from the farms in Buskerud, that are born in between the months March and June and with growth rate between 0.1 kg/day and 0.5 kg/day were selected (Figure 1). The criteria for the litter size were that the ewes from litter 1 to 5 were selected. Selection was based on the deviation from the mean.

Variable	N	Mean	Std Dev	Minimum	Maximum
dam	91683	41931464.30	31961745.93	56655.00	117594318
hy	91683	134281418	14230158.09	6.0000000	149042013
sire	91683	47337303.23	35058549.14	56657.00	108479632
bmonth	91683	4.4975186	0.5049458	3.0000000	6.0000000
grate	91683	0.3238927	0.0528008	0.0993377	0.5233645
lsize_tag	91683	2.3851532	0.7384094	1.0000000	5.0000000
dam_age	91683	2.9895291	1.6291836	1.0000000	8.0000000
animal	91683	65407455.35	36637815.21	14841961.00	120214787
carcassfat_qual	77976	6.4546527	1.6591026	1.0000000	15.0000000

Figure 1. Criteria for the restrictions of data

2.3 Traits studied

The growth trait studied here is the pre weaning ewe lamb body growth rate which is measured in kg/day and denoted as 'growth rate.' It was calculated from ewe's weight at weaning as follows:

Growth rate = weaning weight/ wean age

Wean age is ewe's age at weaning, and it was calculated by subtracting the ewe's birth date (birth_date) from the date of weaning (wean_wdate). Primiparous ewe fertility was measured as age at first lambing (measured in days). This is denoted as 'age at litter' and considered as the measure of age at successful mating in this study. Age at litter is considered equivalent to at mating in this study. The variable carcass fat quality (carcassfat_quality) measured as EUROP score explains the 'fat score.' For ruminants in Norway, EUROP classification is carried out by human assessment of fat class in addition to carcass weight. Fat class describes the amount of visible fat (subcutaneous) on the outside of the carcass. Carcasses are given classes from 1 to 15 and 1for fat class. Grade 15 is 5+ for fat class. High value on fat class indicates a carcass with a high degree of external fat (subcutaneous), and utilizes the relationship between external fat and total fat content of carcass (Johansen et al., 2006). We took account of the fixed effects that is being traditionally taken account of, for genetic evaluation of traits in Norway i.e., herd-year, month when the ewes were born (birth month) and age of the dam (mother of ewe, denoted (dam age). Sex was integrated out of the model because we only considered ewe lambs. The ewes selected were born in the years 2010-2020, between March and June, and weaned between first of August to 20th of October. The weaning age width in the data was 90-180 days (Figure.1). This shows that the data has wider range of acceptance than in the practiced breeding.

2.4 Statistics

Initially, a univariate analysis for each trait (growth rate, age at litter and fat score) was carried out by restricted maximum likelihood model (REML) using the Asreml packages in R, to calculate fixed effects and variance components. In this case, the following models were fitted to the three traits.

$Y_{ijklm} = \mu + herdyear_j + birth\ month_k + dam\ age_l + a_m + eijkl_m$

where Y_{ijklm}= growth rate in kg/day, age at litter in days or fat score, μ = overall mean, $herdyear_j$ = fixed effect of the j^{th} herd-year, birth $month_k$ = fixed effect of the kth month (k=3,4,5,6), dam age_l = fixed effect of the lth age of dam (l=1-8), a_m is the effect of the m^{th} animal and e_{ijkl} = random residual effect.

The model had the following variance-covariance structure for the random effects

$$v \begin{bmatrix} a \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & 0 \\ 0 & I_e\sigma_e^2 \end{bmatrix}$$

where A is the additive relationship matrix and I_e an identity matrix. It was assumed that the additive genetic effects and residual effects had an expectation of 0 and were normally distributed. The fixed effects parameters significance was assessed with a conditional Wald F-test.

Secondly two bivariate analysis was carried out: 1) Bivariant analysis of growth rate and ageatlitter and 2) Bivariate analysis of fat score and age at litter. In both cases the model specification was:

$$\begin{pmatrix} Y_1 \\ Y2 \end{pmatrix} = \begin{bmatrix} X_1 & 0 \\ 0 & X_2 \end{bmatrix} \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} + \begin{bmatrix} Z_1 & 0 \\ 0 & Z_2 \end{bmatrix} \begin{pmatrix} u_1 \\ u_2 \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \end{pmatrix}$$

where Y1 is the vector of observations of growth rate and Y2 is the vector of observations of ageatlitter/fat score, X1 and Z1, are known incidence matrices of growth rate, X2, and Z2 are known incidence matrices of age at litter/fat score, b1 and b2 are the vectors of fixed effects for growth rate and age at litter/fat score, u1 is the vector of random effects for growth rate and u2 is the vector of random effects for ageatlitter/fat score, and. e1 and e2 are vectors of random residual effects of the traits.

The distribution of random effects in both these two scenarios can be written

$$v \begin{bmatrix} a \\ e \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & 0 \\ 0 & I_e\sigma_e^2 \end{bmatrix}$$

$$v\left(\begin{bmatrix} e1 \\ e2 \end{bmatrix}\right) = \begin{bmatrix} I\sigma_{e1}^2 & 0 \\ sym. & I\sigma_{e2}^2 \end{bmatrix}$$

Heritability was calculated with the following equation:

$$h^2 = \frac{\sigma_a^2}{\sigma_a^2 + \sigma_e^2}$$

The genetic correlation was calculated with the following equation:

$$r_A = \frac{COV_{AXY}}{[\sigma^2{}_{aX}\,\sigma^2{}_{aY}\,]^{1/2}}$$

where COV_{AXY} is the genetic covariance between the two traits X and Y. $\sigma^2{}_{aX}$ and $\sigma^2{}_{aY}$ are the additive genetic variances of the traits X and Y.

The environmental correlation was calculated with the following equation:

$$r_A = \frac{COV_{EXY}}{[\sigma^2{}_{EX}\ \sigma^2{}_{EY}\ ]^{1/2}}$$

where COV_{EXY} is the environmental covariance between the two traits X and Y. $\sigma^2{}_{EX}$ and $\sigma^2{}_{EY}$ are the additive environmental variances of the traits X and Y.

3 Results

3.1 Estimated fixed effects

The age at litter, growth trait and the fat score were all significantly influenced by herd year and birth month of ewe with P value greater than 0.01 and F.con value greater than 2 (Table 1). The very small probability (Pr) in the Wald test shows that the fixed effects are highly significant. Wald test result F.con value of birth month was 1762 which is very high showing a very high effect (Figure 1).

Table 1. Results from Wald F test

Fixed effect Parameters	F.con	Pr value
Herd-year	6	0.0000
Birth month	1762	0.0000
Dam age	4	0.0001

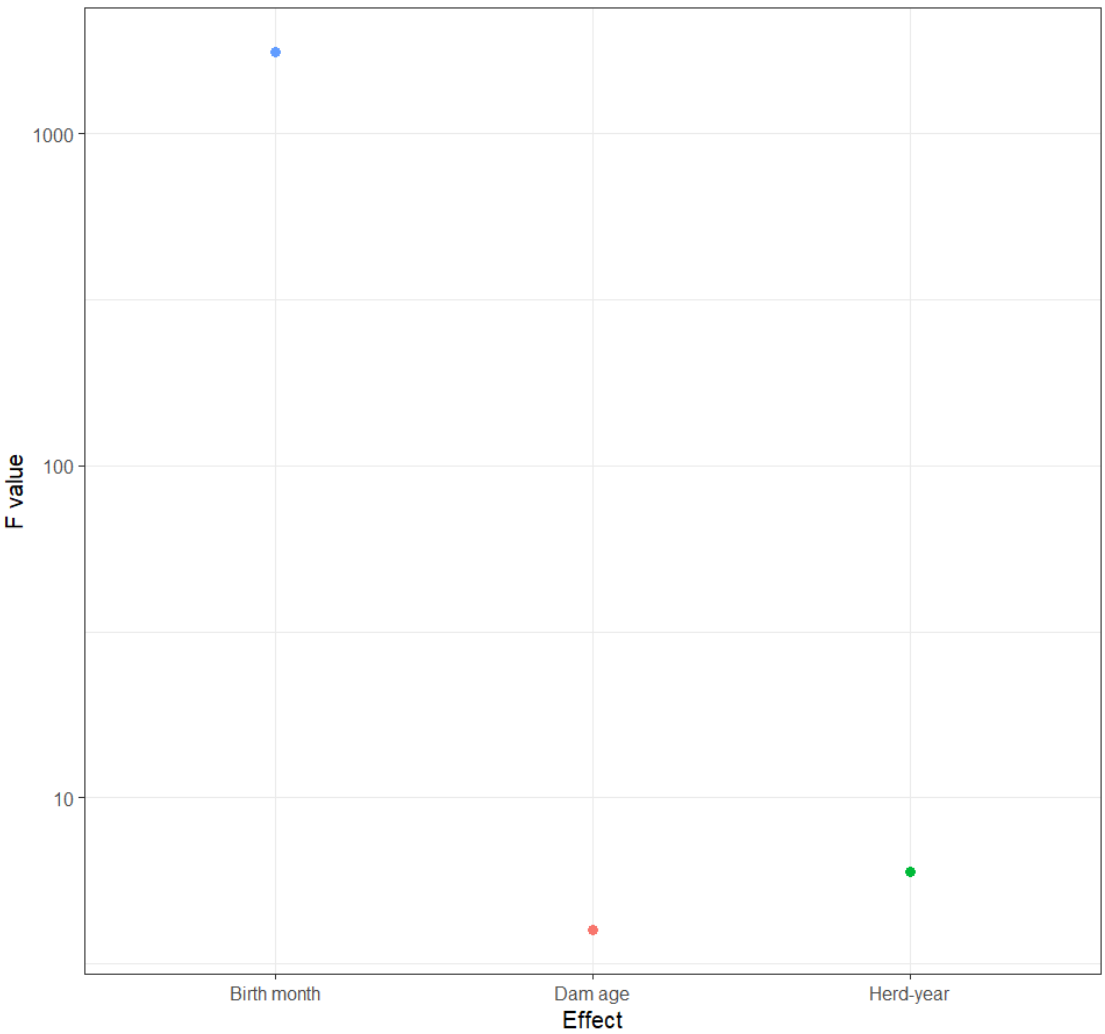

Figure 1. Plot of estimated F.con values for each fixed effect

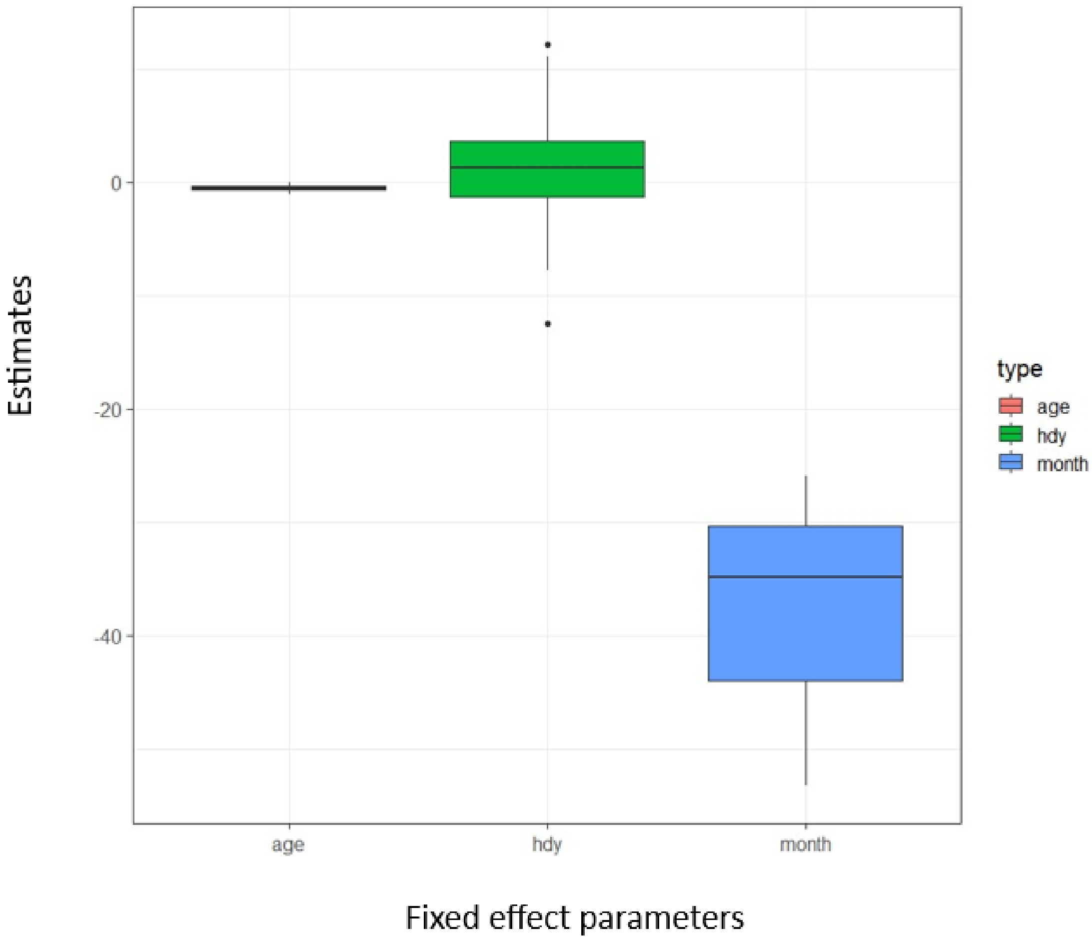

Figure 2. Estimated effects of dam age, herd-year, and ewe birth month

3.2. Variance components and genetic parameters for the traits using bivariate models

Estimates of (co)variance components and genetic parameters for growth rate, age at first litter and fat score obtained by bivariate models are shown in Table 2. All standard errors were small ranging from 0.007 to 0.01. Age at litter, the fertility success trait showed considerable heritability of 0.08. Growth rate showed a heritability of 0.2 and fat score showed a heritability of 0.16 (Table 2).

Table 2. Estimated additive genetic (σ^2_a) and environmental variances (σ^2e) as well as heritability (h2) with its standard error (S.E.) in bivariate analysis of three traits.

Traits	$\boldsymbol{\sigma_a^2}$	$\boldsymbol{\sigma_e^2}$	$\mathbf{h^2}$ **± S. E**
Age at litter	7.12	73.14	0.08±0.009
Growth rate	0.0004	0.001	0.2±0.01
Fat score	0.0003	0.002	0.16± 0.007

3.3 Estimating Additive genetic (r_A) and environmental correlations (r_E) between the traits

The estimated genetic correlation between growth rate and age at litter was -0.16 which is close to zero but negative and the estimated genetic correlation between fat score and age at litter was -0.009 which is again close to zero (Table 3).

Table 3. Estimated additive genetic (rA) correlations between the traits with their standard errors.

Traits	$\mathbf{r_A}$**±S.E**
Growth rate and age at litter	-0.16 ± 0.04
Fat score and age at litter	-0.009 ±0.05

The estimated environmental correlation between growth rate and age at litter was -0.19 which is close to zero but negative and the estimated genetic correlation between fat score and age at litter was -0.02 which is again close to zero (Table 4).

Table 4. Estimated environmental correlations (rE) between the traits with their standard errors.

Traits	$\mathbf{r_E}$ **±S.E**
Growth rate and age at litter	-0.19 ± 0.008
Fat score and age at litter	-0.02 ± 0.008

4 Discussion

In this study, it was assumed that the fertility variable would hardly be heritable, and alternatively one could have analyzed a categorical success variable, whether the ewe lambed or not. However, number of days till lambing was heritable to around 8%, expressing a considerable genetic standard deviation (x days). To my knowledge, the trait has never been analyzed in this population, but previous studies in Rambouillet ewes, the trait was analyzed but with low estimates of heritability (Matos et al., n.d.). One possible explanation for the sizeable heritability is the "Finnship-gene" that is segregating in this population (Rochus et al., 2020), and for which all test rams are genotyped. Rams that are homozygous for the gene is not allowed to be used in breeding, but heterozygotes are. These rams will segregate the gene to 50% of their offspring, on average, and this has the potential to explain parts of the genetic variation in number of days till first lambing if the gene effects the trait.

The consequence of not being aware of this trait, neither phenotypically nor genetically through calculation of gene effects and breeding values, can be genetic drift in the trait due to the practiced ram selection, with selection of a few local elite rams, used intensively in the ram circles. If these by chance express negative genetic values for the trait, this has the potential to explain the complaints received from sheep farmers.

This fertility success trait is only available for those giving birth since mating information is not recorded. This could have allowed to define non-return rates, commonly used as a success trait in livestock. Another alternative would be to define a categorical success trait assuming all animals alive at a certain time point having been mated (0) and those that are not later lambing or being culled based on ultrasonic measurements (steadily more common) as 1, but these traits would be confused by the fact that some ewes are not mated but kept to receive state subsidies if alive in March, the following year. A third alternative would be to utilize culling information recorded in NSR for definition of a categorical trait.

Another hypothesis of this study was that the impaired fertility that is reported by farmers could be due to the selection for growth, with a positive genetic correlation to number of days till first lambing if this selection leads to animals becoming physiologically younger at a given age or genetically negative if lambs that grow better comes into fertility earlier, resulting in fewer number of days till first lambing. The correlation was estimated negative as 0.16, with as standard error of 0.044. Thus, there seems that genetic selection for growth rate does not impair fertility as measured by number of days till first lambing, and that the hypothesized effect of reaching a threshold weight at a given age overwhelms the corresponding for being physiologically younger at the given age.

With no explanation for the impaired fertility from growth, it was tested whether the explanation for impaired fertility of half year-old ewes could be due to a genetic correlation that was different from zero between the EUROP-fat scores of the sibs of the ewes and number of days till lambing for the ewes. The estimate of this genetic correlation was only -0.009± 0.05, rejecting such a genetic relationship. In this analysis, we did not, however, correct for the sex of the lamb, which can have impacted the results.

Growth rate and fat score were estimated with heritability of 0.26 and 0.16, respectively, while the most recent estimates for autumn weight and fat scores used in practical breeding of NWS are 0.12 and 0.34. The estimate was obtained for growth rate, which was not subtracted from their birth weight, while the trait used in practice is autumn weight, corrected simultaneously for the age at weighing as a fixed effect in the mixed model, but which also allows for a curvilinear effect of days till weaning while our trait does not. Moreover, the estimates obtained by the responsible organization (Sau og Geit, NSG) is obtained across the country, while the current was based on data for earlier Buskerud- county, only. All relevant data from a herd was used, while NSG split data within a herd in four, and finally average the estimates. NSG include a total of 14 traits in the analysis, with additive genetic and permanent environmental effect of dam in the model. Our data did not allow the permanent environmental effect to be estimated, nor a genetic covariance between the direct environmental genetic effects. In consequence, the estimates of the heritability became somewhat different than those used in practice. This could also have influenced the genetic correlations which should be re-estimated with more data, with the fixed and random structure in the mixed model as used in practice.

The heritability for growth rate shown by our analysis is greater than that of a lot of previous literatures. The heritability for growth rate found out by (Eikje, 1975) was 0.12. As pointed out by (Eikje, 1975)heritability estimates obtained for such deviations may be biased downwards, and will to some extent be dependent on the structure of the data. A well-balanced design with respect to flocks and sires gives less bias. Because of the present breeding program for sheep in Norway, the number of ewe sires per flock has been increasing, and the distribution of daughters of the same sire on all flocks within a ram circle has become more even. It is therefore not surprising that the heritability estimates for records expressed as deviations from the flock averages have shown some increase by time.

A high fat score is useful for sustaining pregnancy in ewes (Walkom et al., 2016) since reproduction requires energy. A human pregnancy requires about 50,000 calories over and above normal metabolic requirements (Frisch, 1984). During lactation, the ewe will draw energy from the energy reserves of her body to meet the energy requirements of the body (Walkom et al., 2016). Thus, a threshold amount of body fat is required to sustain pregnancy. Also, studies in humans show that during sexual maturation or puberty, the body require a lot of calories and these calories are mainly stored as fat reserves. Another finding about body fat during the adolescent spurt is of special interest. Fat increases linearly with increasing lean body weight for all subjects at menarche and at spurt initiation, but at both events fat increases at a slower rate with increasing lean body weight in late maturers than in early maturers. This explains why late maturing girls had less fat on the average at each event than did early maturers, although they did not differ in lean body weight (Frisch, 1984). Since fat converts androgens to oestrogens, the relative degree of fatness is directly related to both the quantity of circulating oestrogen and its biological effectiveness, because body weight influences the metabolism of oestrogen to its most potent or least potent forms (Frisch, 1984). Therefore, higher fat score might correlate with higher reproductive success. Hence, selection against fat, which is currently preferred by the farmers and consumers in Norway, might influence fertility. The value of selecting for increased genetic merit in fat cannot be determined without exploring the genetic relationships with key performance traits of the breeding ewe. The genetic relationship between ewe body condition and fat score with reproduction traits is poorly reported in literatures.

Conclusions

Our study shows that age at litter is a heritable trait and thus should be given more focus in the sheep breeding goal. The genetic correlation between growth rate/fat score and age at first lambing is close to zero which means that selection for increase in growth and low fat does not seem to impair fertility at around a half year of age. Therefore, ewes can lamb when they are 1 year old without affecting the current objectives of the sheep industry – on the contrary, such a strategy would make positive steps towards economic and environmental sustainability. The goal of strong reproductive performance in the first year of life is within reach, as is a major step up in the lifetime reproductive performance of each ewe.

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