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Genetic and phenotypic analysis of reproductive traits in the Murciano-Granadina does: Predictive ability of the statistical models and estimation of genetic parameters

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ABSTRACT

In the present study, data collected between 2016 and 2022 from a private dairy farm of the Murciano-Granadina goat breed, in Ghale-Ganj city, located in the southern area of Kerman province, Iran was used for model comparison and estimation of genetic parameters for reproductive performance. Studied reproductive traits included litter size at birth per doe kidding (LSB), litter size at weaning per doe kidding (LSW), total litter weight at birth per doe kidding (TLWB), and total litter weight at weaning per doe kidding (TLWW). Four univariate animal models comprising various combinations of direct additive genetic, animal permanent environmental, and service sires effects were fitted for each trait. The predictive ability of models was evaluated by applying the predictive ability measure including the mean square of error (MSE) and the Pearson's correlation coefficient between observed and predicted values ($r(y,\hat{y})$) through a two-fold cross-validation study. For LSW, TLWB, and TLWW, the model with direct additive genetic, animal permanent environmental, and service sires effects had the lowest MSE and the highest values for $r(y,\hat{y})$ than other models. For LSB, the model included direct additive genetic and animal permanent environmental was identified as the best model among the tested models. The posterior means for heritability estimates of the studied traits were low values of 0.02 ± 0.01, 0.07 ± 0.01, 0.02 ± 0.01, and 0.03 ± 0.01 for LSB, LSW, TLWB, and TLWW, respectively. The posterior means for repeatability estimates were 0.04 ± 0.01, 0.08 ± 0.02, 0.03 ± 0.01, and 0.04 ± 0.01 for LSB, LSW, TLWB, and TLWW, respectively. The posterior means for the ratio of service sires variance to phenotypic variance (S^2) for LSW, TLWB, and TLWW were 0.09 ± 0.02, 0.02 ± 0.01, and 0.02 ± 0.01, respectively. Genetic correlation estimates were high in magnitude and ranged from 0.69 ± 0.09 (LSB-TLWW) to 0.97 ± 0.02 (LSB-LSW). Phenotypic correlations were low to medium estimates and ranged from 0.17 ± 0.01 (TLWB-TLWW) to 0.55 ± 0.02 (LSB-LSW). Because of low heritability estimates for the studied reproductive traits in the Murciano-Granadina goat breed genetic progress resulting from direct genetic selection for these traits is likely to be slow and improvement in environmental conditions is of great importance for improving the reproductive performance. No genetic and phenotypic antagonism were found among the studied traits. Therefore, it should be possible to simultaneously improve these traits.

1. Introduction

Goats are known for their ability to suit various environmental conditions and production systems that may be undesirable for other livestock species (Oliveira et al., 2016) and are the most prolific of all domestic ruminants under tropical and sub-tropical conditions (Mia et al., 2013). The Murciano-Granadina goat breed is a well-recognized dairy breed in Spain that has been exported to several parts of the world countries (Martinez et al., 2010). The breed of Murciano-Granadina goat was synthesized in 1975 from the Murciana

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and Granadina goat breeds in the semi-arid districts in southeastern Spain. The major visual specifications of the Murciano-Granadina goat breed comprise a straight or sub-concave profile, and a medium-sized body with a tendency to lengthen with black or brown uniform coat color (Delgado et al., 2017).

The reproductive performance of animals is one of the most significant prerequisites for improving production efficiency in any given environment and breeding system (Mia et al., 2013) and also may be regarded as a main factor influencing the productivity and economic viability of commercial goat farms (Mellado et al., 2006). For a long period, improving the milk, fat, and protein production, along with the morphological traits, were the main target breeding characteristics in breeding programs of Spanish dairy goats (Mendendez-Buxadera et al. 2010). Much emphasis on these traits, while ignoring other characteristics such as reproductive ones, may result in unfavorable influences on the health and fertility of animals, which consequently decreases their longevity (Oltenacu and Broom, 2010). The classical antagonistic genetic-environmental relations between milk production and reproductive traits have been well documented in cows (Andersen-Ranberg et al. 2005), sheep (David et al. 2008), and goats (Montaldo et al. 2010). Therefore, the significance of considering reproductive characteristics in genetic selection programs of dairy goats has been increased, as a way of taking these adverse effects into account because of the selection of highly productive females (Ziadi et al., 2021). On the other hand, improvement of the reproduction traits supports the increase of the selection intensity and genetic gain of production traits (Abegaz et al. 2002; Bagnicka et al. 2007). Also, Schmidt et al. (2019) pointed out that improving the reproductive efficiency of domestic animals is important and highly influenced by selection intensity and production costs.

An increase in production efficiency can be attained from goats since they have high reproductive performance with the possibility for increased litter size and shorter generation intervals relative to other livestock (Safari et al., 2007). The process of reproduction in domestic animals is regulated by both genetic and environmental factors, and the net effect of all these influences determines the level and efficiency of reproductive performance (Mellado et al., 2006). Reproductive ability is a complex composite characteristic influenced by several factors such as puberty, estrus, ovulation, fertilization, pregnancy, parturition, lactation, and mothering ability (Atoui et al., 2018). Developing effective breeding and selection programs needs knowledge of the genetic parameters and environmental factors for economically significant traits (Atoui et al., 2018). Moaeen-Ud-Din et al. (2008) remembered that the reproductive efficiency of goats can be determined according to the number of live-born kids and their body weights at birth and weaning. The estimates of genetic parameters for reproductive traits in several goat breeds including Markhoz (Rashidi et al., 2011), Egyptian Zaraibi (Moawed and Shalaby, 2018), South African Angora (Snyman, 2020) and crossbred Alpine × Beetal (Sahoo et al., 2023) were well documented.

In 2015, about 3000 Murciano-Granadina goats were imported from Spain to the southern region of Iran by a private enterprise. This primary purpose was to improve the production efficiency of low-input and low-output local goat breeding farms and enhance the livelihoods of rural flock holders in the southern areas of the country. To achieve this goal, purebred Murciano-Granadina does and bucks were distributed to local flocks or considered for crossbreeding with local goat breeds in the area. The estimates of genetic and phenotypic parameters for the various measures of reproductive performance in the Murciano-Granadina breed, which are required for designing an appropriate breeding program, are still limited.

Reproductive traits in goats such as litter size at birth or at weaning and total litter weight at birth or at weaning per doe kidding are repeatable traits. Thus, a repeatability model which considers individual permanent environmental effects over direct additive genetic effects may provide more accurate estimates of variance components and genetic parameters for these traits. Furthermore, the influence of service sires effects on the expression of doe reproductive traits was also reported (Rashidi et al., 2011). Therefore, the purpose of the current investigation was the comparison of different models including combinations of direct additive genetic, individual permanent environmental, and service sires effects to estimate variance components and genetic parameters for reproductive traits in a population of Murciano-Granadina goats raised in Iran.

2. Materials and methods

2.1. Data availability and flock management

In this study, pedigree information and data on body weights of Murciano-Granadina kids from birth to weaning, collected between 2016 and 2022, were utilized. The data and pedigree were monitored and kids with wrong information were removed from the dataset. The Murciano-Granadina goat flock studied herein has been managed under an intensive production system on a commercial dairy farm located in Ghale-Ganj City, located in the southern region of Kerman province, Iran. Newborn kids were weighed and ear-tagged at birth, and data on their sex and birth type, as well as the identities of their dams and sire, were registered. Weaning was at approximately 80 days of age. Kids were kept on the farm with their dam and manually fed. Maiden does were exposed to the fertile buck at about 11 months of age and 25 kg live body weights in apart groups with a ratio of 15 does per each fertile buck (Mokhtari et al., 2023).

2.2. Studied traits and statistical analyses

The investigated traits in the current research comprised litter size at birth per doe kidding (LSB), litter size at weaning per doe kidding (LSW), total litter weight at birth per doe kidding (TLWB), and total litter weight at weaning per doe kidding (TLWW). TLWB and TLWW were pre-adjusted for the effect of kid sex by using multiplicative adjustment factors which were specified by applying least squares means of birth and weaning weights of kids, respectively. Descriptive statistics for the traits are shown in Table 1. For these repeatable traits, initially, four univariate animal models were fitted. The matrix notation of the investigated univariate animal models was as follows:

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Z_1a} + \mathbf{e} \qquad \text{Model 1}$$

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Z_1a} + \mathbf{Z}_2 \quad \mathbf{pe} + \mathbf{e} \qquad \text{Model 2}$$

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Z_1a} + \mathbf{Z}_3 \quad \mathbf{s} + \mathbf{e} \qquad \text{Model 3}$$

$$\mathbf{y} = \mathbf{Xb} + \mathbf{Z_1a} + \mathbf{Z}_2 \quad \mathbf{pe} + \mathbf{Z}_3 \quad \mathbf{s} + \mathbf{e} \qquad \text{Model 4}$$

Table 1
Descriptive statistics for the reproductive traits in the Murciano-Granadina goat breed.

Item	Traits[¥]			
	LSB	LSW	TLWB (kg)	TLWW (kg)
No. of does	4192	4192	4192	3151
No. of records	10546	10546	10546	6108
No. of sires	151	151	151	132
No. of dam	483	483	483	343
No. of service sires	339	339	339	309
Mean	1.54	1.40	3.28	12.93
S.D.	0.53	0.56	1.38	5.27
C.V. (%)	34.41	40.00	42.07	40.76
Min.	1.00	0.00	1.10	5.20
Max.	3.00	3.00	11.85	47.40

[¥]LSB: litter size at birth per doe kidding, LSW: litter size at weaning per doe kidding, TLWB: total litter weight at birth per doe kidding, TLWW: total litter weight at weaning per doe kidding.

where, **y** represents the vector of records for the investigated traits; **b**, **a**, **pe**, **s** and **e** stand for vectors of fixed, direct additive genetic, individual permanent environmental, service sires, and the residual effects, respectively. The matrices of **X**, $\mathbf{Z_1}$, $\mathbf{Z_2}$, and $\mathbf{Z_3}$ are design matrices associating corresponding effects to vector **y**. It was assumed $\mathbf{a} \sim N(0, \mathbf{A}\sigma_a^2)$, $\mathbf{pe} \sim N(0, \boldsymbol{I}_{pe}\sigma_{pe}^2)$, $\mathbf{s} \sim N(0, \boldsymbol{I}_s\sigma_s^2)$ and $\mathbf{e} \sim N(0, \boldsymbol{I}_n\sigma_e^2)$. **A** is the numerator relationship matrix. $\mathbf{I_{pe}}$, $\mathbf{I_s}$, and $\mathbf{I_n}$ are identity matrices of appropriate dimensions. Furthermore, σ_a^2, σ_{pe}^2, σ_s^2 and σ_e^2 are direct additive genetic, individual permanent environmental, service sires, and residual variances, respectively. Significance testing of fixed effects including kidding year and doe age at kidding was done by SAS software (SAS, 2004). Tukey-Kramer test was applied to compare the mean of the traits across different levels of the considered fixed effects. During the kidding, the kids were born on different days. But they are all weaned on the same day (weaning was at approximately 80 days of age). Therefore, the kids are weaned at different ages. So, the ages of kids at weaning weight recordings (in days) were fitted as a covariate for TLWW which is specified as the birth date in Table 2.

Bayesian Markov Chain Monte Carlo (MCMC) was performed by applying the THRGIBBSF90 program (Misztal et al., 2002). The length of the Gibbs chains and the burn-in period were specified by visual inspection of the trace plots of posterior samples of the parameters. To estimate genetic and phenotypic correlations among the investigated reproductive traits a multivariate linear-threshold model with 200,000 iterations was run, of which the first 20,000 iterations were discarded as burn-in, and posterior samples from each chain were thinned taking thinning intervals of 20 iterations into account. Hence, 9000 samples remained for calculating features of means and posterior standard deviations of genetic and phenotypic parameters by applying the POSTGIBBSF90 program (Misztal et al., 2002).

To evaluate the predictive ability of the models, for each trait, the dataset was randomly divided five times into two sets, including training (50% of the data set) and testing (retained 50% of the data set) data sets. Then, solutions for all fixed and random effects of the training data were estimated and used to predict records in the test data. The predictive ability of the models was evaluated by using the PREDICTF90 program of Misztal et al. (2002). The predictive performance of the models was evaluated by applying two statistical measures, the mean square of error (MSE) and Pearson's correlation coefficient between observed and predicted values ($r(y,\hat{y})$) in the test data set. The MSE and $r(y,\hat{y})$ values were computed five times and were averaged. The lower the average MSE and the higher the average $r(y,\hat{y})$ value imply the superiority of the model.

Table 2
Least squares mean ± standard error for the reproductive traits in the Murciano-Granadina goat breed.

Traits	Traits[¥]			
	LSB	LSW	TLWB	TLWW
Kidding year	* *	* *	* *	* *
2017	1.61 ± 0.01[a]	1.77 ± 0.05[a]	3.80 ± 0.04[b]	14.34 ± 0.05[a]
2018	1.66 ± 0.01[a]	1.70 ± 0.04[b]	3.93 ± 0.04[a]	13.88 ± 0.04[b]
2019	1.32 ± 0.01[c]	1.61 ± 0.03[c]	3.23 ± 0.03[d]	13.34 ± 0.03[c]
2020	1.43 ± 0.01[b]	1.55 ± 0.03[d]	3.35 ± 0.03[c]	13.01 ± 0.03[d]
2021	1.31 ± 0.01[c]	1.53 ± 0.04[d]	2.94 ± 0.03[e]	12.49 ± 0.03[e]
2022	1.35 ± 0.03[c]	1.49 ± 0.10[e]	3.08 ± 0.07[e]	12.50 ± 0.09[e]
Doe age at kidding (yr)	* *	* *	* *	* *
1	1.16 ± 0.01[d]	1.45 ± 0.05[e]	2.64 ± 0.03[c]	12.05 ± 0.05[f]
2	1.39 ± 0.01[c]	1.51 ± 0.04[d]	3.25 ± 0.03[b]	12.44 ± 0.04[e]
3	1.52 ± 0.01[b]	1.60 ± 0.03[c]	3.68 ± 0.03[a]	13.03 ± 0.03[d]
4	1.56 ± 0.01[a]	1.67 ± 0.03[b]	3.62 ± 0.04[a]	13.36 ± 0.03[c]
5	1.57 ± 0.02[a]	1.69 ± 0.04[b]	3.60 ± 0.05[a]	13.80 ± 0.04[b]
6	1.51 ± 0.04[ab]	1.74 ± 0.07[a]	3.53 ± 0.10[a]	14.87 ± 0.07[a]
Birth date[¥¥]	-	-	-	0.05 ± 0.02*

[¥]LSB: litter size at birth per doe kidding, LSW: litter size at weaning per doe kidding, TLWB: total litter weight at birth per doe kidding, TLWW: total litter weight at weaning per doe kidding.
[¥¥]Regression coefficient on the day of the kid's birth.
Least squares mean with similar letters in each subclass within a column do not differ statistically at $p < 0.01$. * * Significant effect at $P < 0.01$.

3. Results

The Murciana-Granadina goat had a moderate multiple-birth rate of 38% in the present study. The frequencies of single, twin, and triplet kids were 62%, 36%, and 2%, respectively.

3.1. Fixed effects

The least squares means for sub-classes of tested fixed factors including the kidding year and doe age at kidding across the considered traits are present in Table 2. All the studied traits were significantly affected by kidding year and doe age ($P < 0.01$). The ages of kids at weaning weight recordings (in days) significantly influenced TLWW ($P < 0.05$).

3.2. Model comparison

As shown in Table 3, the predictive ability of models was compared by using MSE and $r(y,\hat{y})$. For LSW, TLWB, and TLWW, the model included direct additive genetic, animal permanent environmental, and service sires effects (model 4) had the lowest MSE and the highest $r(y,\hat{y})$ values than other models and was identified as the best model for genetic analysis of these traits among the considered models. But for LSB, the model with direct additive genetic and animal permanent environmental effects (model 2) was selected as the best model among the tested models.

3.3. Univariate analyses

Posterior means for the variance components and genetic parameters of the investigated traits applying the best univariate model are presented in Table 4. Posterior means for heritability estimates of the studied traits were low and statistically significant (95% of the highest posterior density (HPD) intervals did not include zero), and ranged from 0.02 for LSB and TLWB to 0.07 for LSW. Posterior means for repeatability estimates of the studied reproductive traits of the Murciano-Granadina goat breed were statistically significant (95% HPD intervals did not include zero) and low values of 0.04, 0.08, 0.03, and 0.04 for LSB, LSW, TLWB, and TLWW, respectively. The posterior means for the ratio of service sires variance to phenotypic variance (S^2) for LSW, TLWB, and TLWW were 0.09, 0.02, and 0.02, respectively. These estimates were statistically significant (95% HPD intervals did not include zero).

3.4. Multivariate analysis

Posterior means for genetic and phenotypic correlation estimates among the reproductive traits are presented in Table 5. All estimated genetic and phenotypic correlations were positive and statistically significant (95% HPD intervals did not include zero). Genetic correlation

Table 3
Predictive ability of models considered for genetic analysis of reproductive traits in the Murciano-Granadina goat breed.

Model[a]	Traits[¥]							
	LSB		LSW		TLWB		TLWW	
	MSE[¥¥]	r (y,ŷ)[¥¥]	MSE[¥¥]	r (y,ŷ)[¥¥]	MSE[¥¥]	r (y,ŷ)[¥¥]	MSE[¥¥]	r (y,ŷ)[¥¥]
Model I	2.76	0.31	2.59	0.45	1.64	0.37	24.71	0.35
Model 2	**2.57**	**0.38**	2.59	0.47	1.62	0.39	24.47	0.37
Model 3	2.76	0.33	2.58	0.49	1.60	0.42	24.12	0.39
Model 4	4.12	0.33	**2.28**	**0.54**	**1.57**	**0.49**	**23.84**	**0.41**

[¥] LSB: litter size at birth per doe kidding, LSW: litter size at weaning per doe kidding, TLWB: total litter weight at birth per doe kidding, TLWW: total litter weight at weaning per doe kidding.
[¥¥] MSE: mean square of error, (r(y,y´): the Pearson's correlation coefficient between observed and predicted values
For each trait, the best model is shown in boldface.

Table 4
The estimates of genetic parameters for reproductive traits in the Murciano-Granadina goat breed form univariate analyses.

Trait[¥]	σ_e^2 [¥¥]	σ_p^2 [¥¥]	$h^2 \pm$ PSD[¥¥]	r ± PSD[¥¥]	$S^2 \pm$ PSD[¥¥]
LSB	0.26	0.28	0.02 ± 0.01	0.04 ± 0.01	-
LSW	0.23	0.28	0.07 ± 0.01	0.08 ± 0.02	0.09 ± 0.02
TLWB	1.63	1.70	0.02 ± 0.01	0.03 ± 0.01	0.02 ± 0.01
TLWW	25.04	26.61	0.03 ± 0.01	0.04 ± 0.01	0.02 ± 0.01

[¥] LSB: litter size at birth per doe kidding, LSW: litter size at weaning per doe kidding, TLWB: total litter weight at birth per doe kidding, TLWW: total litter weight at weaning per doe kidding.
[¥¥]σ_e^2: residual variance, σ_p^2: phenotypic variance, h^2: heritability, r = repeatability, S^2: ratio of service sires variance to phenotypic variance. PSD: Posterior standard deviation

Table 5
Genetic correlations (above) and phenotypic correlation (below) among the studied reproductive traits in the Murciano-Granadina goat breed.

Traits[¥]	LSB	LSW	TLWB	TLWW
LSB	-	0.97 ± 0.02	0.88 ± 0.05	0.69 ± 0.09
LSW	0.55 ± 0.02	-	0.94 ± 0.03	0.81 ± 0.06
TLWB	0.30 ± 0.01	0.31 ± 0.01	-	0.92 ± 0.02
TLWW	0.21 ± 0.02	0.31 ± 0.01	0.17 ± 0.01	-

[¥] LSB: litter size at birth per doe kidding, LSW: litter size at weaning per doe kidding, TLWB: total litter weight at birth per doe kidding, TLWW: total litter weight at weaning per doe kidding.

estimates were high in magnitude and ranged from 0.69 (LSB-TLWW) to 0.97 (LSB-LSW). Phenotypic correlations among the studied traits were low to medium estimates and lower than the corresponding genetic correlations. These estimates ranged from 0.17 (TLWB-TLWW) to 0.55 (LSB-LSW).

4. Discussion

The significant influence of kidding year on the considered reproductive traits can be justified partly by variations in climatic conditions during the study period. There was a general tendency for the improvement of all the traits with the increase of doe age at kidding. Variations in maternal effects, nursing and maternal behavior of does at various ages justifying the significant effects of doe age at kidding on kid body weight at birth and weaning used in calculation TLWB and TLWW. Rashidi et al. (2011) reported the significant influence of kidding year and doe age at kidding on LSB, LSW, TLWB, and TLWW of Markhoz goats.

Rashidi et al. (2011) compared several models including different combinations of direct additive, individual permanent environmental, and service sires effects for the genetic evaluation of reproductive traits in Markhoz goats and reported that the model with direct additive genetic and individual permanent environmental effects was appropriate for LSB and LSW and the model with direct additive genetic effects, individual permanent environmental effects, and service sires effects was appropriate for TLWB and TLWW.

The low heritability estimates obtained for the reproductive traits in the present study are typical for these parameters in various goat breeds (Rashidi et al., 2011; Jembere et al., 2017; Snyman, 2020) and may be explained by low additive genetic variation for these traits in the studied population. Natural selection may be considered as a reason for the low heritability of reproductive measures considered as fitness-related traits (Ziadi et al., 2021). The basic theorem of natural selection explains that the rate of increase in fitness of any organism at any time is equal to its genetic variance in fitness at that time (Fisher, 1930). It has been inferred that traits with the lowest heritability estimates are those most closely associated with fitness characteristics (Ziadi et al., 2021).

Jembere et al. (2017) conducted a meta-analysis study and reported estimates of 0.05, 0.06, and 0.04 for direct heritability of LSB, LSW, and TLWW in goats, respectively. Rashidi et al. (2011) estimated values of 0.01, 0.01, 0.02, and 0.03 for heritability of LSB, LSW, TLWB and TLWW in Markhoz goat, respectively. Estimates of heritability for LSB and TLWB of the Boer goat breed were reported near zero by Menezes et al. (2016). They also reported a direct heritability estimate of 0.10 for TLWW in the Boer goat breed which was higher than the estimated value in the present study. Atoui et al. (2018) reported an estimate of 0.15 for the heritability of LSB in a Tunisian local goat population which was higher than the corresponding estimate in the present study. Snyman (2020) reported low estimates of 0.05, 0.07, and 0.07 for the heritability of LSB, LSW, and TLWW in South African Angora goats, respectively.

Low repeatability estimates obtained in the present study implied low contributions of genetic and permanent environmental effects to the phenotypic variations of studied reproductive traits. Therefore, improving temporary environmental conditions in the flock such as doe nutrition before mating and late pregnancy can result in the improvement of these reproductive characteristics in the studied population of Murciano-Granadina goat. Rashidi et al. (2011) reported low repeatability estimates of 0.07, 0.04, 0.07, and 0.06 for LSB, LSW, TLWB, and TLWW in Markhoz goats, respectively. In another study, Abdoli et al. (2019) estimated a low value of 0.05 for the repeatability of LSB in the Markhoz goat breed. By applying a meta-analysis study, Jembere et al. (2017) reported estimates of 0.06, 0.04, and 0.06 for the repeatability of LSB, LSW, and TLWB in goats. Snyman et al. (2020) reported estimates of 0.08, 0.09, and 0.12 for repeatabilities of LSB, LSW, and TLWW in South African Angora goats, respectively.

Rashidi et al. (2011) estimated values of 0.03 and 0.02 for S^2 of TLWB and TLWW in Markhoz goats, respectively. The effects of service sires are associated with litter weights and with the survival of litter from birth to weaning (Bromley et al., 2001).

Favorable genetic and phenotypic correlations among the studied reproductive traits in the Murciano-Granadina goat breed imply that improving any of these traits will improve others appropriately. Positive and high genetic correlation estimates among LSB, LSW, TLWB, and TLWW of the Murciano-Granadina goat breed imply that genes responsible for the heavier weight of kids at birth through the number and weight of kids may also influence milk production and thus the mothering ability of the does from birth to weaning. Rashidi et al. (2018) also reported a high and positive genetic correlation among LSB, LSW, TLWB, and TLWW in the Markhoz goat breed. Higher estimates for phenotypic correlation among reproductive traits in Markhoz goats were reported by Rashidi et al. (2011) which ranged from 0.59 (LSW-TLWB) to 0.77 (LSB-TLWB). Such differences may be justified by factors such as breed differences and the structure of data employed for genetic evaluation.

5. Conclusions

The direct additive genetic, individual permanent environmental, and service sires effects were important sources of variation for LSW, TLWB, and TLWW in the studied population of the Murciana-Granadina goat breed. For LSB, the direct additive genetic and individual permanent environmental effects were important. Although the studied reproductive traits are important ones for developing an efficient breeding program, genetic progress resulting from direct genetic selection for these traits is likely to be slow and improvement in environmental conditions is of great importance for improving the reproductive performance in the studied population of Murciano-Granadina goat breed. No genetic and phenotypic antagonism were found among the studied traits. Therefore, it should be possible to simultaneously improve these traits.

CRediT authorship contribution statement

Mokhtari Morteza: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Software, Writing – original draft, Writing – review & editing. **Gutierrez Juan Pablo:** Conceptualization, Methodology, Validation. **Mohebbinejad Ehsan:** Data curation, Writing – original draft. **Roudbari Zahra:** Formal analysis, Methodology, Writing – original draft. **Barazandeh Arsalan:** Methodology, Software. **Esmailizadeh Ali:** Conceptualization, Methodology, Validation, Writing – review & editing. **Mirmahmoudi Rouhollah:** Conceptualization, Validation, Writing – original draft.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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