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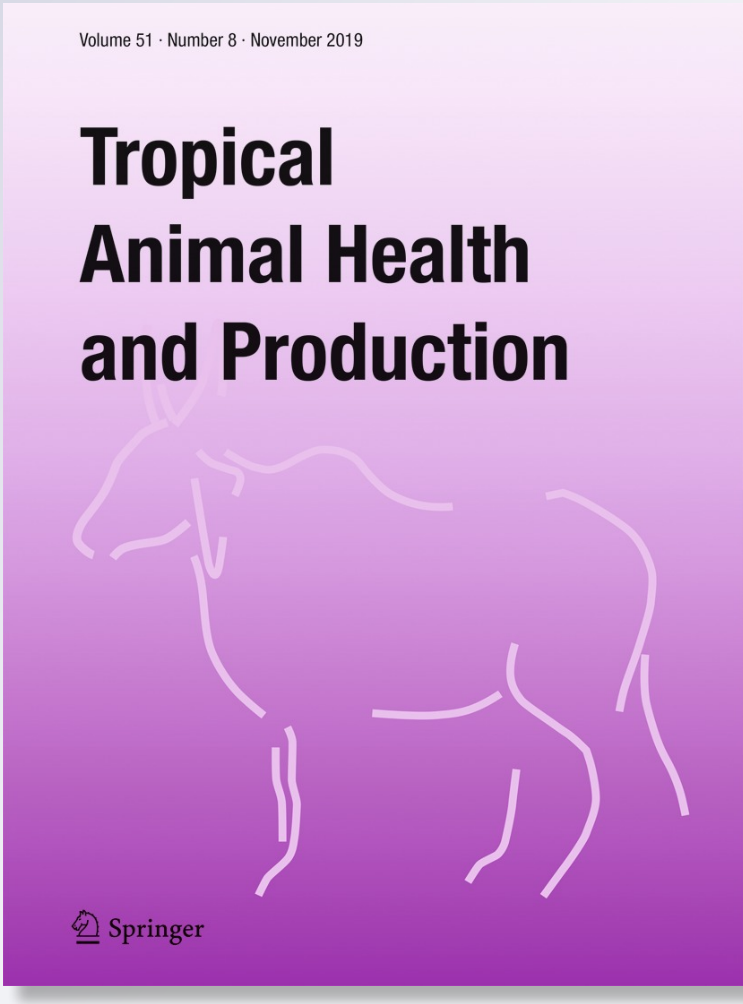

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REGULAR ARTICLES

Genetic and phenotypic aspects of early reproductive performance in Raeini Cashmere goats

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Abstract
This study used pedigree information and data collected from 1979 to 2012 at the Raeini Cashmere goat breeding station, located in Baft City in Kerman Province in southeastern Iran. Genetic and phenotypic parameters for early reproductive traits of breeding does, including total numbers of kids born at first kidding (LSB1), total numbers of kids weaned at first kidding (LSW1), total birth weight of all kids born at first kidding (LWB1), total weaning weight of all kids weaned at first kidding (LWW1), and age at first kidding (AFK), were estimated using a Bayesian approach via Gibbs sampling. Posterior means for heritability estimates of LSB1, LSW1, LWB1, LWW1, and AFK were statistically significant, with values of 0.12, 0.23, 0.17, 0.15, and 0.46, respectively. Low-to-moderate additive genetic variation was present for the studied reproductive traits. Estimated genetic correlations among LSB1, LSW1, LWB1, and LWW1 were statistically significant and ranged from 0.12 between LWB1 and LWW1 to 0.72 between LSB1 and LSW1. Corresponding phenotypic correlation estimates were also statistically significant and ranged from 0.04 between LWB1 and LWW1 to 0.55 between LSB1 and LSW1. Posterior means of genetic and phenotypic correlations between AFK and other studied traits were statistically significant only for LSB1 and LWB1. For LSB1, LSW1, LWB1, and LWW1, we conclude that genetic and phenotypic improvement in any of these traits in Raeini Cashmere does would favorably influence all of the other traits. However, does that first kidded at younger ages have smaller litters at birth and lower litter birth weights at their first parity.

Keywords Litter size · Litter weight · First kidding · Raeini Cashmere doe

Introduction

The Raeini Cashmere goat is a small-sized native Iranian breed that produces white, light brown, and dark brown Cashmere. The Raeini Cashmere goat is a dual-purpose breed, producing both meat and Cashmere, and is mainly found in southern and southeastern Iran. Approximately 2 million Raeini Cashmere goats are present in Iran, typically in small flocks managed in low-input production systems and under unfavorable climatic conditions (Maghsoudi et al. 2009). Small ruminant animals such as goats play an important role in the livelihood of flock holders and are mainly kept under extensive production systems on pastures with low quality and quantity (Kosgey and Okeyo 2007). In these systems, poor reproductive performance is one of the major factors influencing the efficiency of goat production and is also considered to be a primary limitation for setting up optimal production systems (Menezes et al. 2016).

Goats are reared under a variety of production systems and climatic conditions and have great genetic diversity in reproductive potentials (Notter 2012). Cinkulov et al. (2009) stated that the reproductive traits are the main traits determining productivity and profitability in goat breeding programs, especially for meat production. Traits such as the number of live-born kids and the body weights of kids at birth and weaning may be used to measure reproductive efficiency in

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goats (Song et al. 2006; Moaeen-ud-din et al. 2008). Snowder (2008) pointed out that the expression of genetic effects on reproduction is affected by numerous environmental factors such as season, climatic conditions, management, and age of dam. Therefore, the reproductive process is determined not only by genetic factors but also by environmental ones, and the net effect of all these influences determines the level and efficiency of reproduction (Mellado et al. 2006). Because genetic and environmental factors interact, genetic improvement of reproduction is very complicated. Notter (2000) pointed out that the improvement of reproductive traits could potentially reduce production costs.

Knowledge of genetic parameters for economically important traits such as reproductive performance is required to develop efficient genetic improvement programs (Safari et al. 2005). Traits such as litter size at birth, litter size at weaning, litter weight at birth, litter weight at weaning, and age at first kidding were considered to be useful measures of reproductive performance (Kebede et al. 2012; Mia et al. 2013; Deribe and Taye 2014). However, reported estimates of heritability for reproductive traits in goats were generally low (Hamed et al. 2009; Mia et al. 2013; Menezes et al. 2016). As a result, selection based on the reproductive performance of the parents is of little value for genetic improvement (Mellado et al. 2005). Measurement of differences between poor and efficient reproducers early in the life of the individual is instead preferred in order to improve productivity in goat flocks (Mellado et al. 2005). Therefore, the measurement of reproductive traits during the first reproductive cycle may be useful (Mellado et al. 2005), providing opportunity for early life selection of goats and increasing the rate of genetic improvement.

To our knowledge, there were no estimates of genetic parameters for early reproductive performance in Raeini Cashmere goats, even though this information is necessary to develop an efficient breeding program in this breed. The objective of the present study was therefore to estimate genetic and phenotypic parameters for reproductive traits at the first parity of Raeini Cashmere does.

Materials and methods

Flock management and studied traits

The Raeini Cashmere goats used in this study were reared under semi-intensive management conditions which were similar to prevailing conditions in nomadic flocks of the region. Mating occurred from August to October, and the corresponding kidding period lasted from January to March.

Pedigree information for the study was collected from 1979 to 2012 at the Raeini Cashmere goat breeding station in Baft, in Kerman Province in the southeastern part of Iran. The early reproductive traits of Raeini Cashmere does included the total numbers of kids born at first kidding (LSB1), total numbers of kids weaned at first kidding (LSW1), total birth weight of all kids born at first kidding (LWB1), total weaning weight of all kids weaned at first kidding (LWW1), and age at first kidding (AFK). Descriptive statistics for the studied traits are presented in Table 1.

Statistical analyses

The GLM procedure of SAS (version 9.1, SAS Institute, Inc., Cary, NC, USA; SAS 2004) was used to determine the fixed effects to be included in a model for genetic evaluation of the studied traits. Birth and weaning weight records of kids were adjusted for the effect of the sex of the kid using multiplicative adjustment factors before calculation of LWB1 and LWW1. Fixed effects included in the final models were the birth year of the doe and the first kidding year of the doe. The multivariate model for genetic evaluation of the studied traits was fitted as

$$\mathbf{y_i} = \mathbf{X_i b_i} + \mathbf{Z_i a_i} + \mathbf{e_i}$$

where $\mathbf{y_i}$ is a vector of records for the studied traits, $\mathbf{b_i}$, $\mathbf{a_i}$, and $\mathbf{e_i}$ are vectors of fixed, direct additive genetic, and residual effects, respectively, and $\mathbf{X_i}$ and $\mathbf{Z_i}$ are design matrices associating the corresponding effects with $\mathbf{y_i}$.

LSB1 and LSW1 were analyzed using threshold models with two (1, 2) and three (0, 1, 2) categories, respectively. Bayesian Markov chain Monte Carlo implementation was performed using the THRGIBBS1F90 program (Misztal et al. 2002). The multivariate analysis was performed via Gibbs sampling to evaluate the posterior density of the parameter estimates. For this purpose, 100,000 iterations were run and posterior samples from each chain were thinned every 10 iterations after discarding the first 10,000 iterations as burn-in. Hence, 9000 samples were used for computing features of the posterior distribution. The length of the chain and the burn-in

Table 1 Descriptive statistics for the studied early reproductive traits in Raeini Cashmere goats

Trait[¥]	No. of records	Mean	SD	Min.	Max.	CV (%)
LSB1	1570	1.10	0.32	1	2	29.09
LSW1	1570	0.80	0.55	0	2	68.75
LWB1 (kg)	1570	2.49	0.70	1.20	5.70	28.11
LWW1 (kg)	1368	11.30	4.47	3.10	41.00	39.56
AFK (months)	1570	19.66	6.58	10	33	33.47

[¥] *LSB1*, total number of kids born at the first kidding of a doe; *LSW1*, total number of kids weaned at the first kidding of a doe; *LWB1*, total birth weight of kids born at the first kidding of a doe; *LWW1*, total weaning weight of kids weaned at the first kidding of a doe; *AFK*, age at the first kidding of a doe period were inspected by visual examination of trace plots of posterior samples of the parameters. Posterior analysis for calculating posterior means and posterior standard deviations and convergence checking were performed using the POSTGIBBSF90 program (Misztal et al. 2002).

Solutions for direct additive effects were assumed, a priori, to have a multivariate normal distribution with the null mean vector and (co)variance matrix $\mathbf{G} \otimes \mathbf{A}$, where $\mathbf{G}$ and $\mathbf{A}$ are the genetic (co)variance matrix among traits and numerator relationship matrix among individuals, respectively, and $\otimes$ indicates the Kronecker product. The vector of residual effects was assumed to have a multivariate normal distribution with the null mean vector and (co)variance matrix $\mathbf{R} \otimes \mathbf{I_n}$, where $\mathbf{I_n}$ is an identity matrix and $\mathbf{R}$ is the residual (co)variance matrix among traits. The prior distribution of $\mathbf{G}$ was assumed to be an inverted Wishart distribution, and its fully conditional posterior distribution was therefore also an inverted Wishart distribution (Sorensen and Gianola 2002).

Results and discussion

General considerations

The reproductive traits considered in the present study were obtained at the first kidding of Raeini Cashmere goats. Published information on the reproductive traits of goat breeds at the first kidding is limited, and comparison of results obtained in the present study (Table 1) with those obtained for other breeds over several kidding periods may be useful. Means for LSB1 and LSW1 in Raeini Cashmere goats were 1.10 and 0.8 kids, respectively, at the first kidding. At the first kidding, these goats therefore produced mainly single kids, with occasional twins (9.16% of all births) and a very low frequency of triplet births. These means were lower than those reported for litter size at birth and (or) weaning in several goat breeds (Song et al. 2006; Bagnicka et al. 2007; Hamed et al. 2009; Mia et al. 2013). Mia et al. (2013) reported that litter sizes at birth and weaning in Black Bengal does increased as parity progressed, with the lowest litter sizes at birth and at weaning at the first parity. Bagnicka et al. (2007) reported values of 1.51 and 1.23 for litter size at the first kidding for Polish and Norwegian goat breeds, respectively, which were higher than the corresponding estimates in the present study. Means for litter size at weaning for Boer (Zhang et al. 2009) and Korean native (Song et al. 2006) goats were 1.62 and 1.52, respectively. Low means for LSB1 and LSW1 in the present study imply that Raeini Cashmere goats have either lower ovulation rates or poorer embryo and (or) fetal survival at the first pregnancy compared with other native goat breeds and also have comparatively low survival rates of kids during the first parity. Approximately 27% of first-parity Raeini Cashmere does lost their kids before weaning. The corresponding survival rate of 73% at weaning for kids born in first-parity Raeini Cashmere does suggests that improving the maternal ability of first-parity dams and the associated viability of their kids is a priority for Raeini Cashmere goats. The associated mortality from birth to weaning of Raeini Cashmere kids may be ascribed to factors such as the incidence of epidemic diseases as well as the deficiency of vaccination. Similar mortality rates were reported in Kil and Angora breeds of Turkey (Gursoy 2005) and Baladi breed of Lebanon (Khazaal 2005).

The body weight of kids at birth is an economically important trait (Cinkulov et al. 2009). In the present study, the mean total birth weight of kids born at the first parity to Raeini Cashmere does was 2.49 kg. Reported values for average litter weight of kids at birth were often higher than those obtained at the first kidding of Raeini Cashmere does, but this result may, in part, be explained by a limited uterine space in first-parity does. Zhang et al. (2009) reported an average litter weight at birth in Boer kids of 6.54 kg. The litter weaning weight is determined mainly by the litter size at birth, the viability of the kids from birth to weaning, individual potentials of kids for growth, and the mothering ability (i.e., milk production and maternal behavior) of the doe. In the present study, the average for total body weight of kids weaned at the first parity was 11.30 kg. By contrast, the average litter weight at weaning for Markhoz goats was reported to be 21.9 kg (Rashidi et al. 2011). However, there is a lack of published information on body weight of kids at birth and at weaning that is specific to the first kidding.

The mean value for AFK in Raeini Cashmere goats was 19.66 months (Table 1). Cinkulov et al. (2009) reported a lower value of 13 months for age at first kidding in German Fawn goats. A value of 17.2 months was obtained for age at first kidding in Creole goats (Alexandre et al. 1999) which was relatively close to the mean obtained in the present study. A lower value for AFK is important for two reasons: first, a shorter generation interval allows correspondingly higher rates of genetic progress and, second, an early first kidding can increase lifetime production (Cinkulov et al. 2009). Ages at the first kidding as low as 9.5 months were reported for Sicilian goats (Lanza et al. 1990), but very late ages (i.e., 21 to 25 months of age in Indian goats) have also been reported (Gill and Dev 1972). Bagnicka et al. (2007) reported means for AFK of 13.89 and 13.63 months for Polish and Norwegian goat breeds, respectively, which were lower than the mean for Raeini Cashmere goats in the present study.

Heritability estimates

Posterior means, posterior standard deviations (PSD), and corresponding 99% highest posterior density (HPD) intervals for heritability estimates for early reproductive traits in Raeini Cashmere goats are shown in Table 2. Heritability estimates

Table 2 Posterior means ± posterior standard deviation (PSD) for heritability estimates of the studied early traits in Raeini Cashmere goats

Trait[¥]	h^2 ± PSD	99% highest posterior density interval
LSB1	0.12 ± 0.01**	0.09–0.14
LSW1	0.23 ± 0.05**	0.10–0.36
LWB1	0.17 ± 0.01**	0.14–0.19
LWW1	0.15 ± 0.04**	0.05–0.25
AFK	0.46 ± 0.05**	0.33–0.59

[¥] *LSB1*, total number of kids born at the first kidding of a doe; *LSW1*, total number of kids weaned at the first kidding of a doe; *LWB1*, total birth weight of kids born at the first kidding of a doe; *LWW1*, total weaning weight of kids weaned at the first kidding of a doe; *AFK*, age at the first kidding of a doe

**99% highest posterior density interval did not include zero

were moderate and statistically significant (i.e., 99% HPD intervals did not include zero) and ranged from 0.12 for LSB1 to 0.46 for AFK.

Estimates of heritability for litter size at the first parity are limited for goat breeds. Bagnicka et al. (2007) reported estimates of 0.14 and 0.18 for heritability of litter size at the first parity in Polish and Norwegian goat breeds, respectively, which were in agreement with the estimate of 0.17 from the present study. Heritability estimates for litter size at birth across all doe ages in Boer (Zhang et al. 2009) and Arsi-Bale goats (Kebede et al. 2012) were 0.12 and 0.074, respectively. Heritability estimates for litter size at weaning in different goat breeds were generally low. Heritability estimates for litter size at weaning in Arsi-Bale (Kebede et al. 2012), Boer (Zhang et al. 2009), and Zaraibi (Hamed et al. 2009) goats were 0.006, 0.10, and 0.05, respectively. In general, heritability estimates for litter size at birth and weaning for small ruminants are low, indicating that phenotypic variation in these traits is controlled mainly by environmental and, perhaps, non-additive genetic variation.

Heritability estimates for LWB1 and LWW1 were moderate, with values of 0.17 and 0.15, respectively. There are few published heritability estimates for total litter weight of kids for first-parity does. In a previous study, a heritability estimate for LWW1 for first-parity Raeini Cashmere does of 0.072 was reported by Maghsoudi et al. (2009) and was lower than the corresponding estimate of 0.20 from the present study. The difference may be explained, in part, by differences between the data sets and the methodology. Heritability estimates for average litter weight at birth in Arsi-Bale (Kebede et al. 2012) and Boer (Zhang et al. 2009) goats were 0.125 and 0.14, respectively, and were reasonably consistent with estimates from the current study.

The heritability of AFK in US dairy goats was estimated to be 0.16 (Castaneda-Bustos et al. 2014), which was lower than the estimated value of 0.46 in the present study. Heritability estimates for AFK in Polish, Mexican, and Arsi-Bale goats were 0.13 (Bagnicka et al. 2007), 0.31 (Torres-Vazquez et al. 2009), and 0.245 (Kebede et al. 2012), respectively. These results suggest that selection is a viable tool for modifying AFK in Raeini Cashmere goats. A heritability estimate of 0.49 was also reported for AFK in Anglo-Nubian goats (Lobo and da Silva 2005), and a review study by Shrestha and Fahmy (2007) reported a range of 0.48 to 0.56 for the heritability of AFK in different goat breeds.

Correlation estimates

Posterior means and PSD for genetic, phenotypic, and residual correlations among the studied early reproductive traits are shown in Table 3. Estimates of genetic correlations among LSB1, LSW1, LWB1, and LWW1 were statistically significant and ranged from 0.12 between LWB1 and LWW1 to 0.72 between LSB1 and LSW1. Corresponding phenotypic correlation estimates were also statistically significant and ranged from 0.04 between LWB1 and LWW1 to 0.55 between LSB1 and LSW1, implying that genetic and phenotypic improvement in any of these traits would favorably influence the other traits.

In a previous study, Rashidi et al. (2011) also found positive genetic and phenotypic correlations between litter size at birth and litter size at weaning and between total litter weight at birth and total litter weight at weaning in Markhoz goats. In general, any improvement in LSB1 in the Raeini Cashmere goat would improve LSW1, LWB1, and LWW1 accordingly. Rashidi et al. (2011) also found high genetic and phenotypic

Table 3 Posterior means ± posterior standard deviation (PSD) for direct genetic (r_g), phenotypic (r_p), and residual (r_e) correlation estimates between the studied early reproductive traits in Raeini Cashmere goats

Pair traits[¥]	r_g ± PSD	r_p ± PSD	r_e ± PSD
LSB1-LSW1	0.72 ± 0.13**	0.55 ± 0.03**	0.65 ± 0.03**
LSB1-LWB1	0.32 ± 0.08**	0.10 ± 0.02**	0.38 ± 0.05**
LSB1-LWW1	0.41 ± 0.09**	0.46 ± 0.02**	0.55 ± 0.03**
LSB1-AFK	0.80 ± 0.04**	0.12 ± 0.03**	− 0.37 ± 0.06**
LSW1-LWB1	0.40 ± 0.14**	0.10 ± 0.03**	− 0.12 ± 0.08^{ns}
LSW1-LWW1	0.25 ± 0.06**	0.18 ± 0.03**	0.17 ± 0.05**
LSW1-AFK	0.02 ± 0.13^{ns}	0.02 ± 0.03^{ns}	0.02 ± 0.08^{ns}
LWB1-LWW1	0.12 ± 0.01**	0.04 ± 0.01**	− 0.07 ± 0.05^{ns}
LWB1-AFK	0.22 ± 0.07**	0.16 ± 0.03**	0.05 ± 0.12^{ns}
LWW1-AFK	− 0.10 ± 0.14^{ns}	− 0.03 ± 0.03^{ns}	− 0.01 ± 0.06^{ns}

[¥] *LSB1*, total number of kids born at the first kidding of a doe; *LSW1*, total number of kids weaned at the first kidding of a doe; *LWB1*, total birth weight of kids born at the first kidding of a doe; *LWW1*, total weaning weight of kids weaned at the first kidding of a doe; *AFK*, age at the first kidding of a doe

^{ns} 95% highest posterior density interval included zero

**99% highest posterior density interval did not include zero correlations between litter size at weaning and total litter weight at birth and weaning in Markhoz goats.

Phenotypic and genetic correlation estimates between LWB1 and LWW1 were low but positive (0.04 and 0.12, respectively). The total birth weight of kids born at the first parity of a Raeini Cashmere doe therefore was only lowly correlated with the corresponding total weaning weight of the kids. Residual correlations were 0.65, 0.55, 0.38, and 0.17 between LSB1 and LSW1, LSB1 and LWW1, LSB1 and LWB1, and LSW1 and LWW1, respectively. These estimated correlations were statistically significant, but residual correlations between LSW1 and LWB1 and between LWB1 and LWW1 were not significant.

Posterior means for genetic and phenotypic correlations between AFK and other studied traits (except LSB1 and LWB1) were not statistically significant. However, genetic and phenotypic correlation estimates between LWB1 and AFK were significant (0.22 and 0.16, respectively). The corresponding genetic and phenotypic correlation estimates between LSB1 and AFK were also significant (0.80 and 0.12, respectively). Raeini Cashmere does that were younger at the first kidding therefore would be expected to produce smaller litters and have lower litter birth weights at their first parity. Selection to reduce AFK would correspondingly need to be coupled with positive selection on LSB1 and LWB1 to maintain productivity in does kidding at younger ages. Changes in the management of first-parity does could likewise assist in avoiding reductions in LSB1 and LWB1 in does that kid at younger ages.

Conclusions

Substantial levels of phenotypic variation but low-to-moderate heritability estimates for numbers and cumulative weights of kids at birth and weaning would limit the accuracy of breeding value estimates for individual does and for individual sires but would permit reasonable rates of genetic improvement across the entire population of goats. Posterior means for genetic and phenotypic correlation estimates among these traits were positive, and selection for any of the traits would result in a corresponding improvement in the others. By contrast, age at first kidding had both high levels of phenotypic variation and a relatively high heritability estimate, indicating that substantial genetic progress could be achieved for this trait and would, most importantly, potentially reduce the proportion of does that failed to kid in their second year of life. However, reducing AFK was predicted to have small negative genetic and phenotypic effects on LSB1 and LWB1, potentially requiring positive selection on these traits or changes in the management of first-parity does to maintain doe productivity.

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Compliance with ethical standards

All applicable international, national, and/or institutional guidelines for the care and use of animals were followed.

Conflict of interest The authors declare that they have no conflict of interest.

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