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Estimation of the autosomal and sex-linked genetic parameters for growth rate and efficiency-related traits in Moghani sheep

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Abstract In the present study, data on growth traits of Moghani sheep breed, collected during 1988 to 2011 at Jafarabad Breeding Station, were used. The studied traits were average daily gain from birth to weaning (ADG1), average daily gain from weaning to six months of age (ADG2), average daily gain from six months of age to yearling age (ADG3), Kleiber ratio from birth to weaning (KR1), Kleiber ratio from weaning to six months of age (KR2), Kleiber ratio from six months of age to yearling age (KR3), growth efficiency from birth to weaning (GE1), growth efficiency from weaning to six months of age (GE2), and growth efficiency from six months of age to yearling age (GE3). Genetic and phenotypic parameters were estimated for autosomal and sex-linked components of the studied traits under animal model. Direct autosomal heritability estimates for ADG1, ADG2, ADG3, KR1, KR2, KR3, GE1, GE2 and GE3 were 0.09±0.01, 0.07±0.02, 0.03±0.01, 0.13±0.02, 0.09±0.02, 0.02±0.01, 0.07±0.01, 0.06±0.01 and 0.02±0.01, respectively. Pre-weaning traits were not influenced by sex-linked additive genetic components. Sex-linked heritability estimates for ADG2, KR2, GE2, ADG3, KR3 and GE3 were 0.04±0.01, 0.02±0.01, 0.02±0.01, 0.02±0.01, 0.02±0.01 and 0.03±0.01, respectively. The autosomal additive genetic correlations between traits ranged from -0.68±0.22 for ADG3-KR1 and ADG1-GE2 to 0.99±0.01 for KR3-GE3. The sex-linked additive genetic correlations among traits were positive and varied from 0.14±0.02 for GE2-ADG3 to 0.98±0.01 for ADG3-KR3 and KR3-GE3. Results revealed that when sex-linked effects are important, genetic analysis using an animal model which accounts for both autosomal and sex-chromosome inheritance provides more accurate estimates of the variance components for the post-weaning traits studied in this research.

Keywords: growth efficiency, maternal effects, lambs, X-chromosome linked effects

Introduction

Meat production is one of the most important aspects of breeding enterprises in Iran. Sheep production in Iran has relied mainly on ranges of low quality and quantity. During the recent years, the area of rangelands has decreased at an alarming rate due to destruction by human activities as well as significant decreases in annual precipitation and the occurrence of long periods of drought (Sefidbakht, 2011). Genetic selection of the best animals for body

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weight recorded at different ages is a possible way in increasing the meat production (Boujenane and Kansari, 2002). Body weight of domestic animals at different ages has deterministic effects on the profitability of breeding enterprises. Therefore, such characteristics may be considered as efficient selection criteria in any breeding systems (Tosh and Kemp, 1994).

In the developing countries native breeds of the small ruminants are mainly kept by local farmers under low-input production systems. Under such systems the livelihood of the flock holders mainly depends on the promotion of production efficiency (Kosgey and Okeyo, 2007). Therefore, coordinated attempts in terms of managerial practices and genetic improvement programs are of crucial importance. Appropriate selective procedure based on the breeding values requires accurate estimates of the genetic parameters. Maximizing the rate of genetic change through selection strategies mainly depends on well-defined breeding objectives and accuracy of estimated genetic parameters for decisive traits.

In mammalian species, the X-chromosome is a part of the XY sex-determination system. The X-chromosome constitute of 155 million base pairs and carries 1098 genes of which the function of a few numbers is known (Ross et al., 2005). Previous investigations showed the contribution of sex-linked loci to phenotypic variation of quantitative traits such as body weight (Rance et al., 1997). Therefore, it is important to separate sex-linked additive genetic components from autosomal ones. While, VanRaden (1987) reported that at least 5% to 10% of the genetic variation in milk and in fat production can be explained by X-chromosomal gene effects, due to lack of suitable software, for years these effects were ignored from livestock genetic evaluation models (see for example Kariuki et al, 2010; Mandal et al. 2015 and Singh et al. 2016). The assumption of only autosomal inheritance may result in inflated estimates of what should be interpreted as autosomal additive genetic variance. The latter occurs due to the similarities in the inheritance patterns and thus the (co)variance structure of the autosomal and sex-linked genes (Grossman and Eisen, 1989). Ghafouri-Kesbi and Abbasi (2019) stated that if sex-linked genetic components have decisive effects on a trait, ignoring them can decrease the accuracy of genetic evaluation because these components are masked by autosomal genetic effects.

There are limited reports on the estimation of sex-linked related genetic parameters for growth traits in sheep (Maraveni et al., 2018; Ghafouri-Kesbi and Abbasi, 2019; Mohammadi and Latifi, 2020).

In a previous study genetic parameters were estimated for growth traits in Moghani sheep breed (Jafaroghli et al., 2010). But there is no information on the genetic parameters of growth efficiency-related traits while autosomal and sex-linked additive genetic components are taken into account. Due to the importance of growth efficiency-related traits for developing efficient breeding programs especially for sheep breeds which are kept on the poor ranges, knowledge of accurate genetic parameters for these traits are required. Therefore, the objective of present study was to estimate the autosomal and sex-linked genetic components for average daily gain and growth efficiency-related traits in Moghani sheep.

Materials and methods

Data and flock management

Pedigree information used in the present study were collected during 1988 to 2011 at Jafarabad Breeding Station of Moghani sheep, located in north-west of Iran. A summary of the pedigree structure is shown in Table 1. Other information collected were birth year, sex, birth type, and the identification number of newborn lambs and their parents. Health care and veterinary practices including, vaccination and antiparasitic drugs administration, were done according to the station's routine protocol.

The flock was kept on the summer range from May to October, and on the winter range from November to April. Breeding season started from August and lasted to October, using a controlled mating system so that the identity of sire and dam of each lamb was known. Under the controlled mating system, ewes were organized into groups of 10-15 heads and in a breeding period each group was allocated to a fertile ram; approximately 30-35 fertile rams were used annually for mating. In the next breeding period, each group of ewes was mated to a different ram. In other words, rams were used rotationally among ewe groups. Ewe lambs and ram lambs were bred at 18 months of age. Rams were used only for 1 year, while ewes could be used for up to 8 years. Lambs were weaned at approximately 3 months of age. Male and female lambs were kept in separate flocks from the age of 6 months onwards. Breeding animals were selected in July, primarily based on the general appearance and coat color. Lambing period ranged from January to February.

The studied traits

Records on live body weights at birth (BW), weaning (WW), six months of age (SIXW) and yearling weight (YW) were used for calculation of the traits. The investigated traits were average daily gain from birth to weaning (ADG1), average daily gain from weaning to six months of age (ADG2), average daily gain from six months of age to yearling age (ADG3), Kleiber ratio from birth to weaning (KR1) as ADG1/WW$^{0.75}$, Kleiber ratio from weaning to six months of age (KR2) as ADG2/SIXW$^{0.75}$, Kleiber ratio from six months of age to yearling age (KR3) as ADG3/ YW$^{0.75}$, growth efficiency from birth to weaning (GE1) as (WW-BW/BW)×100, growth efficiency from weaning to six months of age (GE2) as (SIXMW-WW/WW) ×100 and growth efficiency from six months of age to yearling age (GE3) as (YW-SIXW/SIXW)×100. The structure of the data set is presented in Table 2.

Statistical analysis

Common fixed effects included in the animal models were sex of lambs in 2 classes (male and female), dam age at lambing in 7 classes (2-8 years old) and birth type in 3 classes (single, twin, and triplet). For the studied traits, birth year was in 23 classes (1988-2011).

To study the role of autosomal and sex-linked additive genetic effects in genetic evaluation of the traits, a restricted maximum likelihood (REML) procedure under a derivative free algorithm was used eight models including different combinations of autosomal additive genetic, sex-linked additive genetic and maternal (maternal additive and maternal permanent) effects were tested applying WOMBAT program (Meyer, 2013). The considered models (in matrix notation):

$y = Xb + Z_1a + e$ Model 1

$y = Xb + Z_1a + Z_1s + e$ Model 2

$y = Xb + Z_1a + Z_2pe + e$ Model 3

$y = Xb + Z_1a + Z_1s + Z_2pe + e$ Model 4

$y = Xb + Z_1a + Z_3m + e$ $\quad Cov(a,m) = 0$ Model 5

$y = Xb + Z_1a + Z_1s + Z_3m + e$ $\quad Cov(a,m) = 0$ Model 6

$y = Xb + Z_1a + Z_2pe + Z_3m + e$ $\quad Cov(a,m) = 0$ Model 7

$y = Xb + Z_1a + Z_1s + Z_2pe + Z_3m + e$ $\quad Cov(a,m) = 0$ Model 8

where, **y** is a vector of records for the trait; **b, a, s, m**, **pe** and **e** are vectors of fixed, autosomal additive genetic (i.e. additive genetic effects related to genes located on autosomal chromosomes), sex-linked additive genetic (i.e. additive genetic effects related to genes located on X chromosome), maternal additive genetic, maternal permanent environmental and the residual effects, respectively. **X, Z_1, Z_2** and **Z_3** are design matrices associating corresponding effects to vector of **y**. Also, **A** is the numerator relationship matrix. The Akaike's Information Criterion (AIC) was applied for the determination of the most appropriate model among tested models (Akaike, 1974):

$$AIC_i = -2 \log L_i + 2 P_i$$

where, $\log L_i$ is the maximized log likelihood and p_i is the parameters fitted for model i. In each case, the model with the lowest AIC was considered as the best model.

Results and discussion

The structure of pedigree and data is shown in Tables 1 and 2, respectively. Approximately, 89% of the registered animals had both parents known, which indicated high quality of the considered pedigree (Table 1). Pre-weaning traits, including ADG1, KR1 and GE1, were higher than the corresponding post-weaning traits of ADG2, KR2 and GE2. Because of maternal support during the suckling period, lambs are less influenced by the environmental factors; however the post-weaning stress may decrease the growth of lambs. Such trend has been reported by Ghafouri-Kesbi and Gholizadeh (2017) in Baluchi lambs. Furthermore, traits measured in the pre-weaning growth phase had the smallest phenotypic coefficients of variation (C.V.) compared to those of post-weaning phase. It may be due the stress of weaning and greater influence of the environmental factors after weaning.

Table 1. Summary of the pedigree structure

Item	Numbers
Total animals in pedigree	14977
Sires	423
Sires with progeny	245
Dams	4216
Dams with progeny	1438
Animals with progeny	4639
Animals with no progeny	10338
Animals with both parents known (non-founders)	13294
Animals with both parents unknown (founders)	1683
Inbred animals	2407
Average inbreeding coefficient in all animals	0.006
Average inbreeding coefficient in the inbred animals	0.037

Model comparisons

The AIC values for each model and trait are presented in Table 3 with the most appropriate model shown in the bold face. For pre-weaning traits, including ADG1, KR1 and GE1, the model which included direct additive, maternal additive genetic and maternal permanent environmental effects (Model 7) was selected as the most appropriate one. In other words, sex-linked additive genetic effects had no influence on the pre-weaning traits in Moghani sheep.

For ADG2, KR2 and GE2, the model which included autosomal, sex-linked direct additive and, maternal additive genetic effects (Model 6) was the most appropriate for genetic analysis. However, for the remaining traits (ADG3, KR3, GE3), the model that included the autosomal and sex-linked direct additive genetic and maternal permanent environmental effects (Model 4) was the most appropriate one. Maternal additive genetic effects contributed significantly to the trait variation from birth to six months of age, which disappeared afterwards. Maternal permanent environmental effects were important for genetic evaluation of the studied traits from birth to weaning and from six months of age to yearling age. In general, in agreement with other reports (Ghafouri-Kesbi and Gholizadeh, 2017; Gafouri-Kesbi and Abbasi, 2019), the results showed that fitting the maternal effects to the data was substantially more advantageous than fitting a simple additive model.

Table 2. Descriptive statistics for the studied traits in Moghani sheep

Item	Traits ¥								
	ADG1	ADG2	ADG3	KR1	KR2	KR3	GE1	GE2	GE3
No. of records	9900	7986	4796	9900	7986	4796	9900	7986	4796
Mean	202.32	114.35	31.39	19.02	7.96	1.90	427.56	46.95	16.77
SD	47.17	41.50	20.80	2.30	2.56	1.14	106.29	21.67	11.69
CV (%)	23.31	36.29	66.26	12.09	32.16	60.00	24.86	46.15	69.71
No. of dams with records	3440	3214	2409	3440	3214	2409	3440	3214	2409
Average number of progenies per dam	2.88	2.48	1.99	2.88	2.48	1.99	2.88	2.48	1.99
No. of sire with records	336	327	308	336	327	308	336	327	308
Average number of progenies per sire	29.46	24.42	15.57	29.46	24.42	15.57	29.46	24.42	15.57

¥ ADG1: average daily gain from birth to weaning; ADG2: average daily gain from weaning to six months of age; ADG3: average daily gain from six of age to yearling age, KR1: Kleiber ratio from birth to weaning; KR2: Kleiber ratio from weaning to six months of age; KR3: Kleiber ratio from six months of age to yearling age; GE1: growth efficiency from birth to weaning; GE2: growth efficiency from weaning to six months of age; GE3: growth efficiency from six months of age to yearling age

Table 3. AIC values for the studied traits under different models

Model	Traits ¥								
	ADG1	ADG2	ADG3	KR1	KR2	KR3	GE1	GE2	GE3
Model 1	82140.17	64388.15	31889.23	23548.13	20068.29	4457.23	100366.69	54067.56	26720.34
Model 2	82141.29	64389.61	31889.80	23549.04	20069.36	4456.19	100366.17	54065.30	26719.02
Model 3	82076.24	64384.18	31879.15	23507.56	20069.12	4453.38	100241.36	54061.13	26717.38
Model 4	82078.05	64383.93	**31877.45**	23508.48	20067.94	**4451.44**	100242.49	54062.52	**26715.17**
Model 5	82087.12	64383.47	31879.15	23521.78	20066.18	4454.93	100268.45	54059.29	26717.27
Model 6	82088.03	**64382.54**	31878.74	23521.22	**20064.99**	4453.63	100269.14	**54058.45**	26716.58
Model 7	**82072.65**	64384.78	31888.14	**23488.10**	20067.26	4452.29	**100235.62**	54062.68	26719.39
Model 8	82074.19	64385.49	31887.31	23489.85	20066.85	4453.43	100237.62	54060.24	26717.15

¥ ADG1: average daily gain from birth to weaning; ADG2: average daily gain from weaning to six months of age; ADG3: average daily gain from six to yearling age, KR1: Kleiber ratio from birth to weaning; KR2: Kleiber ratio from weaning to six months of age; KR3: Kleiber ratio from six months to yearling age; GE1: growth efficiency from birth to weaning; GE2: growth efficiency from weaning to six months of age; GE3: growth efficiency from six months of age to yearling age

Univariate analyses

The estimates of genetic parameters under the best univariate selected model are presented in Table 4. Autosomal heritability (h^2) estimates were low for all traits and ranged from 0.02±0.01 for KR3 and GE3 to 0.13±0.01 for KR1. Autosomal heritability estimates for ADG1, ADG2 and ADG3 were 0.09±0.02, 0.07±0.01 and 0.03±0.01, respectively. Ghafouri-Kesbi and Abbasi (2019) estimated the autosomal heritability for pre- and post-weaning average daily gain in Makooei sheep as 0.17 and 0.09, respectively, which are close to the present estimates for Moghani sheep. However, the estimated autosomal heritability value of 0.22 for pre-weaning average daily gain from birth to weaning in Zandi sheep (Mohammadi and Latifi, 2020), was higher than the corresponding estimated value in the present study.

The Kleiber ratio, calculated in a definite period, is the growth rate scaled by metabolic weight at the final of the period and can be considered as an indirect selection criterion for improvement of feed efficiency and growth traits under extensive breeding systems (Abegaz et al., 2005). Selection for increased body weights in lambs usually leads to increased mature weight and nutritional requirements for mature ewes. Furthermore, such selection practice increases the sensitivity to environmental factors such as drought, and decreases the rate of reproduction (Lasslo et al., 1985). Thus, selection based on the Kleiber ratio has been suggested as a means of addressing the mentioned issues, as it will impose less selection pressure on the mature weight of animals.

Autosomal heritabilities for KR1, KR2 and, KR3 were 0.13±0.02, 0.09±0.02 and, 0.02±0.01, respectively. Ghafouri-Kesbi and Abbasi (2019) estimated autosomal heritability for the pre- and post-weaning Kleiber ratios in Makooei sheep as 0.13 and 0.08, respectively, which are in agreement with the estimated values in the present study. Mohammadi and Latifi (2020) reported autosomal heritability estimate of 0.29 for the pre-weaning Kleiber ratio in Zandi sheep, which is higher than our estimate. Autosomal heritability estimates of GE1, GE2 and GE3 were 0.07±0.01, 0.06±0.01 and, 0.02±0.01, respectively. Ghafouri-Kesbi and Abbasi (2019) estimated the autosomal heritabilities for the pre- and post-weaning growth efficiency rates in Makooei sheep as 0.07 and 0.10, respectively, which are in agreement with estimates in the present study.

A decreasing trend for autosomal heritability was observed from the first growth phase (birth to weaning) to the third growth phase studied (six months of age to yearling age), which shows that the role of genes with additive effects on the expression of the traits decreased from birth to yearling age. Generally, the low estimated autosomal heritability values for the studied traits implied the low possibility of genetic improvement by direct selection. In other words, any improvement in the studied traits of Moghani sheep mainly required improving in non-genetic factors. The efficiency-related traits are important traits in sheep production and any improvement in these traits has a significant impact on profitability of sheep production especially in intensive systems where the cost of feed is high (Gholizadeh and Ghafouri-Kesbi, 2015).

For traits measured in the pre-weaning growth phase, estimated values of s^2 (the ratio of variance related to sex-linked effects to phenotypic variance) were non-significant and essentially zero (Table 4). Gafouri-Kesbi and Abbasi (2019) also reported non-significant effects of the X-linked genetic effects on pre-weaning growth and efficiency-related traits in Makuie sheep. For the post-weaning traits, sex-linked heritability was low and ranged from 0.02±0.01 for ADG3, KR2, KR3 and GE2 to 0.04±0.01 for ADG2 (Table 4). However, the estimates of s^2 were smaller than h^2 estimates, which implied that autosomal genetic variation was more pronounced than the sex-linked genetic variation for the post-weaning traits in Moghani sheep.

Table 4. Variance components and genetic parameters ± SE of the studied traits under the best model

Trait ¥	¥¥h^2 ± SE	¥¥s^2 ± SE	¥¥m^2 ± SE	¥¥pe^2 ± SE	σ_p^2
ADG1	0.09±0.01	-	0.03±0.01	0.06±0.01	1523.74
ADG2	0.07±0.02	0.04±0.01	0.04±0.01	-	1193.84
ADG3	0.03±0.01	0.02±0.01	-	0.02±0.01	286.91
KR1	0.13±0.02	-	0.07±0.02	0.06±0.01	4.01
KR2	0.09±0.02	0.02±0.01	0.04±0.01	-	4.55
KR3	0.02±0.01	0.02±0.01	-	0.03±0.01	0.91
GE1	0.07±0.01	-	0.04±0.01	0.09±0.02	9646.58
GE2	0.06±0.01	0.02±0.01	0.05±0.01	-	324.69
GE3	0.02±0.01	0.03±0.01	-	0.03±0.01	96.92

¥ ADG1: average daily gain from birth to weaning; ADG2: average daily gain from weaning to six months of age; ADG3: average daily gain from six months of age to yearling age, KR1: Kleiber ratio from birth to weaning; KR2: Kleiber ratio from weaning to six months of age; KR3: Kleiber ratio from six months of age to yearling age; GE1: growth efficiency from birth to weaning; GE2: growth efficiency from weaning to six months of age; GE3: growth efficiency from six months of age to yearling age ¥¥ h^2: Autosomal direct heritability; s^2: sex-linked heritability; m^2: maternal heritability; pe^2: ratio of maternal permanent environmental effects to phenotypic variance; SE: standard error; σ^2p: phenotypic variance

Table 5. Estimates of autosomal additive genetic (above diagonal) and sex-linked additive genetic (below diagonal) correlations ± SE between the studied traits

Traits ¥	ADG1	ADG2	ADG3	KR1	KR2	KR3	GE1	GE2	GE3
ADG1	-	0.14±0.01	0.65±0.19	0.67±0.08	-0.51±0.15	-0.52±0.18	0.62±0.10	-0.68±0.22	-0.53±0.11
ADG2	-	-	0.52±0.19	-0.10±0.01	0.88±0.05	0.44±0.18	-0.18±0.01	0.98±0.02	0.38±0.13
ADG3	-	0.22±0.02	-	-0.68±0.22	0.26±0.10	0.98±0.03	-0.61±0.20	0.26±0.02	0.97±0.05
KR1	-	-	-	-	0.15±0.03	0.69±0.30	0.13±0.05	0.16±0.03	0.75±0.23
KR2	-	0.95±0.01	0.17±0.02	-	-	0.31±0.11	-0.51±0.16	0.95±0.03	0.26±0.10
KR3	-	0.28±0.02	0.98±0.01	-	0.20±0.02	-	-0.52±0.16	0.45±0.11	0.99±0.01
GE1	-	-	-	-	-	-	-	0.70±0.13	0.49±0.18
GE2	-	0.97±0.02	0.14±0.02	-	0.94±0.01	0.15±0.02	-	-	0.40±0.14
GE3	-	0.31±0.02	0.96±0.01	-	0.22±0.02	0.98±0.01	-	0.15±0.02	-

¥ ADG1: average daily gain from birth to weaning; ADG2: average daily gain from weaning to six months of age; ADG3: average daily gain from six to yearling age, KR1: Kleiber ratio from birth to weaning; KR2: Kleiber ratio from weaning to six months of age; KR3: Kleiber ratio from six months to yearling age; GE1: growth efficiency from birth to weaning; GE2: growth efficiency from weaning to six months of age; GE3: growth efficiency from six months to yearling age

Limited information is available on the estimates of the sex-linked heritability for growth traits in sheep. In Lori-Bakhtiari sheep, Maraveni et al. (2018) estimated s^2 for the body weight at birth, 3, 6, 9 and 12 months of age as 0.01, 0.01, 0.14, 0.09 and 0.04, respectively. Ghafouri-Kesbi and Abbasi (2019) reported sex-linked direct heritability for the post-weaning average daily gain, Kleiber ratio and growth efficiency rate in Makooei sheep as 0.06, 0.04 and 0.07, respectively.

In the present study, maternal genetic effects were important for ADG1, ADG2, KR1, KR2, GE1 and GE2. However, maternal heritability estimates (m^2) were smaller than the direct heritability estimates. Ghafouri-Kesbi and Abbasi (2019) reported maternal heritability estimates of 0.16, 0.15 and 0.13 for pre-weaning ADG, KR and GE in Makooei sheep, being larger than the corresponding values in the present study. Moreover, --- Ghafouri-Kesbi and Gholozadeh (2017) obtained maternal heritability estimates for the pre-weaning ADG, KR and GE in Baluchi sheep as 0.11, 0.11 and 0.04, respectively.

The influence of maternal permanent environmental effects of dam on performance of progenies arising from multiple birth which influences on milk yield of dam, feeding level at late gestations and maternal behavior of the dam (Rashidi et al., 2008).

In the present study, the estimates of pe^2 for ADG1, ADG3, KR1, KR3, GE1 and GE3 were 0.06±0.01, 0.02±0.01, 0.06±0.01, 0.03±0.01, 0.09±0.02 and 0.03±0.01, respectively. Maternal genetic and permanent environmental effects were significant on the average daily gain and efficiency-related traits in Moghani lambs. Therefore, these effects need to be included in the model for genetic evaluation of Moghani sheep. Ghafouri-Kesbi and Gholizadeh (2017) analyzed the growth efficiency-related traits in sheep and showed that these traits are not only determined by their own genetic potential and the environmental factors but also by the maternal effects.

Bivariate analyses

The estimates of autosomal additive and sex-linked additive genetic correlations are presented in Table 5. Sex-linked additive genetic correlations among the pre-weaning traits and those with post-weaning traits were not estimated because pre-weaning traits in Moghani sheep were not influenced by the sex-linked additive genetic component. Autosomal additive genetic correlations were in the range of -0.68±0.22 (KR1-ADG3 and ADG1-GE2) to 0.99±0.01 (KR3-GE3); implying that not all the efficiency traits can be improved simultaneously following selection and for each period, selection should focus on the trait of the greatest importance. Autosomal additive genetic correlations among the same traits at different growth phases were positive. Furthermore, autosomal additive genetic correlations were positive and high for the traits measured in the same period (i.e. among ADG1, KR1 and GE1 which were measured from birth to weaning; among ADG2, KR2 and GE2 which were measured from weaning to six-months of age; and among ADG3, KR3 and GE3 which were measured from six months of age to yearling age) (Table 5).

Sex-linked additive genetic correlations ranged from 0.14±0.02 (ADG3-GE2) to 0.98±0.01 (ADG3-KR3 and KR3-GE3). Sex-linked additive genetic correlations were positive and high for the traits measured in the same period. Such positive and high estimates of the autosomal and sex-limited additive genetic correlations for ADG2-KR2, ADG2-GE2, ADG3-KR3, ADG3-GE3, KR2-GE2 and KR3-GE3 indicated that the same genes control these traits, and that these traits will change in the same direction via genetic selection (Ghafouri-Kesbi and Abbasi 2019).

The estimated phenotypic and residual correlations among the traits measured in the same period (i.e., among ADG1, KR1 and GE1, among ADG2, KR2 and GE2 and among ADG3, KR3 and GE3) were positive and high (Table 6). Phenotypic correlations varied from -0.58±0.01 (ADG1-GE2) to 0.98±0.01 (ADG3-KR3 and KR3-GE3); implying that not all the traits can be improved in the same time following phenotypic selection. The same trend was also observed for the residual correlations. The phenotypic and residual correlations were in general agreement with those reported in Raeini Cashmere goat (Mokhtari et al., 2019). By considering very high and near unity positive autosomal, sex-linked additive genetic and phenotypic correlations for ADG2-GE2, ADG3-KR3, ADG3-GE3, KR2-GE2 and KR3-GE3, it can be concluded that pair traits may be considered largely as the same traits with different definitions.

Table 6. Estimates of phenotypic (above diagonal) and residual (below diagonal) correlations between the studied traits

Traits[¥]	ADG1	ADG2	ADG3	KR1	KR2	KR3	GE1	GE2	GE3
ADG1	-	-0.19±0.01	-0.02±0.01	0.80±0.01	-0.46±0.01	-0.12±0.01	0.68±0.01	-0.58±0.01	-0.16±0.02
ADG2	-0.22±0.01	-	0.18±0.01	-0.12±0.01	0.94±0.01	0.26±0.01	-0.18±0.01	0.96±0.11	0.29±0.01
ADG3	-0.07±0.02	0.22±0.02	-	-0.03±0.01	0.15±0.01	0.98±0.01	-0.06±0.01	0.11±0.02	0.96±0.01
KR1	0.83±0.01	-0.13±0.02	-0.02±0.01	-	-0.25±0.01	-0.02±0.01	0.42±0.01	-0.33±0.01	-0.03±0.01
KR2	-0.47±0.01	0.95±0.01	0.17±0.02	-0.26±0.01	-	0.18±0.01	-0.39±0.01	0.93±0.01	0.19±0.01
KR3	-0.15±0.02	0.28±0.02	0.98±0.01	-0.04±0.02	0.20±0.02	-	-0.12±0.02	0.12±0.02	0.98±0.01
GE1	0.72±0.01	-0.22±0.02	-0.08±0.02	0.49±0.01	-0.42±0.01	-0.13±0.02	-	-0.48±0.01	-0.14±0.01
GE2	-0.58±0.01	0.97±0.02	0.14±0.02	-0.34±0.01	0.94±0.01	0.15±0.02	-0.50±0.01	-	0.13±0.02
GE3	-0.18±0.02	0.31±0.02	0.96±0.01	-0.05±0.02	0.22±0.02	0.98±0.01	-0.14±0.02	0.15±0.02	-

[¥] ADG1: average daily gain from birth to weaning; ADG2: average daily gain from weaning to six months of age; ADG3: average daily gain from six to yearling age, KR1: Kleiber ratio from birth to weaning; KR2: Kleiber ratio from weaning to six months of age; KR3: Kleiber ratio from six months to yearling age; GE1: growth efficiency from birth to weaning; GE2: growth efficiency from weaning to six months of age; GE3: growth efficiency from six months to yearling age

Conclusions

Growth rate and growth efficiency-related traits in Moghani sheep were genetically evaluated considering the importance of the autosomal and sex-linked additive genetic effects. The estimates of autosomal additive heritability were generally low in magnitude and showed little additive genetic variability in these traits which may decrease the efficiency of breeding programs aimed at increasing the biological efficiency in Moghani sheep. Although, the proportion of the variance related to the sex-linked effects was small, since for some traits inclusion of X-linked effects improved significantly the overall property of the model; an animal model which is able to partition the total additive genetic variation into autosomal, sex-linked and maternal effects could yield a more effective genetic selection.

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