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Early growth performance in the Murciano-Granadina goats: insights from genetic and phenotypic analyses

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Abstract

This study investigates the genetic and phenotypic aspects of early growth performance in the Murciano-Granadina goat breed, using data collected between 2016 and 2022 from a private dairy farm in Ghale-Ganj city, located in the southern area of Kerman province, Iran. Pedigree and data information were collected on several early body weight traits, including birth weight (BW), weaning weight (WW), average daily gain (ADG), Kleiber ratio (KR) and growth efficiency from birth to weaning (GE). Nine univariate animal models included direct additive genetic effects and different combinations of maternal effects were compared by using Akaike information criterion (AIC). Among the tested models, the best genetic analysis model for BW, included direct additive, maternal additive, maternal permanent and maternal temporary environmental effects. The best model for ADG, KR and GE included direct additive, maternal permanent and litter effects. For WW, the best model was determined to be one that included direct additive and maternal additive genetic effects. The estimated direct heritabilities were low values of 0.04, 0.07, 0.08, 0.05 and 0.07 for BW, ADG, KR, GE and WW, respectively. The estimates of genetic correlations among the studied traits were positive and low to high in magnitude which ranged from 0.11 for BW-KR to 0.91 for BW-GE. The phenotypic correlations ranged from 0.03 for KR-WW to 0.87 for ADG-KR. The positive correlations observed among the studied growth traits of the Murciano-Granadina goat breed indicate no negative genetic or phenotypic changes associated with selection for these traits.

Introduction

Goats have significant social and economic importance in many parts of the world (Castel *et al*., 2010). They are known for their ability to adapt to various production systems and environments that may be unsuitable for other livestock species (Oliveira *et al*., 2016). The Murciano-Granadina goat breed is a well-known dairy breed in Spain with international importance, having been exported to several countries (Martinez *et al*., 2010). The Murciano-Granadina goat breed was synthesized in 1975 from the Murciana and Granadina goat breeds in the semi-arid areas in southeastern Spain. The main phenotypic characteristics of the Murciano-Granadina goat breed include a straight or sub-concave profile, a medium-sized body with a tendency to lengthen with black or brown uniform coat colour, and 77 cm and 70 cm high at the withers in males and females, respectively (Delgado *et al*., 2017). Factors such as the globalization of the economy are putting pressure on the profitability of dairy goat farms and related activities, including meat production (Zurita-Herrera *et al*., 2011).

The body weight of domestic animals at different ages has an important effect on the profitability of flock holders. Thus, these characteristics may be regarded as important selection criteria in any production system (Tosh and Kemp, 1994). Improving the growth performance of domestic animals requires knowledge on both genetic and non-genetic effects which are necessary for developing efficient breeding programmes. From a genetic point of view, the implementation of an appropriate breeding programme requires accurate estimates of breeding values for animals and genetic parameters for important traits (Zishiri *et al*., 2013). Estimates of genetic parameters for growth traits in several goat breeds have been reported, including Naeini (Baneh *et al*., 2012), Raeini Cashmere (Mohammadi *et al*., 2012; Mokhtari *et al*., 2019), Markhoz (Rashidi *et al*., 2011; Hosseinzadeh Shirzeyli *et al*., 2023), Beetal (Magotra *et al*., 2021) and Inner Mongolia White Arbas Cashmere (Wang *et al*., 2023) breeds.

In livestock, growth-related traits of animals are influenced not only by their genetic potential but also by maternal effects (Wilson and Reale, 2006). Any effects the female parent exerts on the phenotype of its progeny can be considered maternal effects (Falconer and Mackay, 1996). The genotype of the dam and related environmental factors can influence the dam's ability for milk production, health status, intrauterine conditions and mothering ability (Maniatis and Pollott, 2003). Therefore, maternal effects can be divided into genetic and environmental components. The contribution of maternal effects to phenotypic variation among offspring is considered a criterion in selection programmes in various species (Magotra *et al.*, 2021).

In multiparous species such as goats, maternal environmental effects can be partitioned into permanent and temporary components. However, the latter has been ignored in most genetic studies on the growth traits of goat breeds (Tesema *et al.*, 2020; Singh *et al.*, 2022; Hosseinzadeh Shirzeyli *et al.*, 2023). In species having several progenies per parturition, progenies (full sibs) share a common environment that contributes to their similarity, which is a further source of variation among families (Falconer and Mackay, 1996). This similarity refers to common factors such as nutrition, maternal common care and climatic conditions (Abbasi *et al.*, 2012). In general, the effects arised from these common factors are called maternal temporary environmental or common litter effects. They are common among the litters of a specific dam within each birth year of offspring. The importance of including litter effects in models used for genetic evaluation of growth traits of goats well documented (Rashidi *et al.*, 2011; Menezes *et al.*, 2016; Rout *et al.*, 2018). Ghafouri-Kesbi *et al.* (2022) remembered that including the litter effects in model, fitted the data substantially better than corresponding model which excluded this effect.

In 2015, the private sector imported 3000 Murciano-Granadina goats from Spain to the southern region of Iran. This initiative aimed 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 Iran, local farmers often keep goat breeds for their multi-purpose applications, including fibre, meat and milk production. Although the Murciano-Granadina goat breed is primarily considered for dairy production purposes, understanding the genetic and phenotypic aspects of growth performance in this breed can provide the required information for designing appropriate breeding strategies that incorporate both Murciano-Granadina and local goat breeds in the future. In a recently published study, Mokhtari *et al.* (2023) compared non-linear models describing growth trajectory and estimated genetic parameters for growth curve traits in the Murciano-Granadina goats.

The main objective of the present investigation was to estimate the genetic and phenotypic parameters of the early growth performance of the Murciano-Granadina goat breed by quantifying the importance of maternal effects on early growth traits.

Materials and methods

Flock management

The Murciano-Granadina goat flock studied herein has been managed under an intensive production system on a private dairy farm in Ghale-Ganj city, the southern region of Kerman province, Iran. Newborn kids were weighed and ear-tagged at birth, and information on their sex and birth type, as well as the identities of their dam and sire, were recorded. Weaning was at approximately 80 days of age. Kids were kept indoors and manually fed. Maiden does were exposed to the fertile bucks at about 11 months of age and 25 kg live body weights in separate groups with a ratio of 15 does per fertile buck (Mokhtari *et al.*, 2023). Health care and veterinary practices including vaccination and antiparasitic drugs administration were performed according to the flock's routine protocols.

Data collection and evaluated traits

In this study, pedigree information and data on body weights of Murciano-Granadina kids from birth to weaning were collected from multiple parities of does between the years 2016 and 2022. The data and pedigree were carefully screened and edited several times, and lambs with incorrect information were removed from the dataset. The ENDOG v4.8 program was applied for checking errors in the pedigree and preparing it for subsequent analyses (Gutierrez and Goyache, 2005). The pedigree structure of the investigated population is shown in Table 1. Among the registered goats, those with both sire and dam were known (complete recorded pedigree), with both sire and dam were unknown (no recorded pedigree), and with one of the sire and/or dam was known (incomplete recorded pedigree) represented 0.88, 0.11 and 0.01 of all kids, respectively. In the studied population, animals without offspring and animals with offspring were 0.69 and 0.31 of the total registered animals, respectively.

Individuals with body weights outside the range of overall means $\pm 3 \times$ standard deviations (SD) were excluded from the dataset. The investigated traits included birth weight (BW), weaning weight (WW), pre-weaning average daily gain (ADG) calculated as ((WW-BW)/weaning age) $\times$ 1000, pre-weaning Kleiber Ratio (KR) calculated as ADG/WW$^{0.75}$ and pre-weaning growth efficiency (GE) calculated as ((WW-BW)/BW) $\times$ 100. Table 2 presents the descriptive statistics for the growth traits analysed in this study.

Table 1. Pedigree structure of the population of the Murciano-Granadina goat breed

Item	Numbers
Individuals in total	21 785
Inbreds in total	813
Sires in total	448
Dams in total	6398
Individuals with progeny	6846
Individuals with no progeny	14 939
Founders	2288
Individuals with both parents known	19 211
Individuals with both parents unknown	2288
Individuals with one parent unknown	286
Average inbreeding coefficients (%)	0.2
Average inbreeding coefficients in the inbreds (%)	6.8
Maximum of inbreeding coefficients (%)	31.25
Minimum of inbreeding coefficients (%)	0.4

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Table 2. Descriptive statistics for the studied growth traits in the Murciano-Granadina goat breed

Item	Traits				
	BW (kg)	ADG (g/d)	KR (× 1000)[a]	GE	WW (kg)
No. of records	15 043	7031	7301	7301	7301
Mean	2.4	101	17.6	331	10.3
S.D.	0.41	20.9	3.06	88.3	1.35
C.V. (%)	17.1	20.7	17.4	26.7	13.1
Min.	1.1	32.6	8.5	105.7	5.2
Max.	4.2	332	31.6	983.3	23.0
No. of sires	342	307	307	307	307
No. of dams	4193	3037	3037	3037	3037
Average no. of progeny per sire	44	23.8	23.8	23.8	23.8
Average no of progeny per dam	3.6	2.4	2.4	2.4	2.4

S.D., standard deviation; C.V., coefficient of variation; Min., Minimum; Max., Maximum; BW, birth weight; WW, weaning weight; ADG, average daily gain from birth to weaning; KR, Kleiber ratio from birth to weaning; GE, growth efficiency from birth to weaning.
[a]KR values are multiplied by 1000.

Statistical analyses

The general linear model (GLM) procedure of SAS 9.1 software (SAS, 2004) was used to determine significant fixed effects in the models considered for genetic analyses. Tukey-Kramer test was applied to compare the mean of the traits of interest across different levels of the considered fixed effects. Fixed factors considered in the models for the investigated growth traits were the sex of kids in 2 levels (males and females), birth type in 2 levels (single, multiple births), age of dam at kidding in 5 levels (1–5 years old), birth year in 7 levels (2016–2022) and birth month in 12 levels. The ages of kids at weaning weight (in days) were fitted as a linear covariate for WW.

Initially, the impact of maternal effects on the variance components of the traits was evaluated. Models incorporating combinations of direct additive genetic, maternal additive genetic, maternal permanent environmental and maternal temporary environmental or litter (dam within a year) effects (models 1–9) were fit to the growth traits under investigation. The tested models were as follows:

$\mathbf{y = Xb + Z_1a + e}$		**Model 1**
$\mathbf{y = Xb + Z_1a + Z_2pe + e}$		**Model 2**
$\mathbf{y = Xb + Z_1a + Z_3m + e}$	**Cov (a,m) = 0**	**Model 3**
$\mathbf{y = Xb + Z_1a + Z_3m + e}$	**Cov (a,m) =** $\mathbf{A\sigma_{am}}$	**Model 4**
$\mathbf{y = Xb + Z_1a + Z_2pe + Z_4l + e}$		**Model 5**
$\mathbf{y = Xb + Z_1a + Z_2pe + Z_3m + e}$	**Cov (a,m) = 0**	**Model 6**
$\mathbf{y = Xb + Z_1a + Z_2pe + Z_3m + e}$	**Cov (a,m) =** $\mathbf{A\sigma_{am}}$	**Model 7**
$\mathbf{y = Xb + Z_1a + Z_2pe + Z_3m + Z_4l + e}$	**Cov (a,m) = 0**	**Model 8**
$\mathbf{y = Xb + Z_1a + Z_2pe + Z_3m + Z_4l + e}$	**Cov (a,m) =** $\mathbf{A\sigma_{am}}$	**Model 9**

where, **y** represents the vector of records for the investigated traits; **b**, **a**, **m**, **pe**, **l** and **e** stand for vectors of fixed, direct additive genetic, maternal additive genetic, maternal permanent environmental, maternal temporary environmental (litter) and the residual effects, respectively. The matrices of $\mathbf{X}$, $\mathbf{Z_1}$, $\mathbf{Z_2}$, $\mathbf{Z_3}$ and $\mathbf{Z_4}$ are design matrices associating corresponding effects to vector **y**. It was assumed $\mathbf{a} \sim N(0, \mathbf{A}\sigma_a^2)$, $\mathbf{m} \sim N(0, \mathbf{A}\sigma_m^2)$, $\mathbf{pe} \sim N(0, \boldsymbol{I_{pe}}\sigma_{pe}^2)$, $\mathbf{l} \sim N(0, \boldsymbol{I_l}\sigma_l^2)$ and $\mathbf{e} \sim N(0, \boldsymbol{I_n}\sigma_e^2)$. **A** is the numerator relationship matrix, σ_{am} shows covariance between direct additive and maternal additive genetic effects. $\mathbf{I_{pe}}$, $\mathbf{I_l}$ and $\mathbf{I_n}$ are identity matrices of appropriate dimensions. Furthermore, σ_a^2, σ_m^2, σ_{pe}^2, σ_l^2 and σ_e^2 are direct additive genetic, maternal additive genetic, maternal permanent environmental, maternal temporary environmental (litter) and residual variances, respectively. The best model for each trait was determined by applying the Akaike information criterion (AIC) (Akaike, 1974), which was computed as follows:

$$AIC = -2 \text{ Log L} + 2p$$

where Log L is the maximized Log of likelihood and p is the number of parameters to be estimated by the model. For each trait, the model with the lowest AIC was considered the most appropriate. The estimates of genetic, phenotypic and residual correlations between the studied traits were obtained by applying bi-variate animal models, by using the best univariate animal model determined for each trait. Genetic analyses were performed using the WOMBAT program (Meyer, 2013).

Results

The coefficient of variation was lowest for WW (13.11%) and highest for GE (26.66%). Male and female kids accounted for approximately 0.48 and 0.52 of the newborn kids, respectively. A similar trend was observed for the proportion of male and female kids at weaning. Single-born and multiple births kids comprised around 0.42 and 0.58 of the newborn kids, respectively.

Non-genetic effects influencing the studied growth traits

The least squares means of the investigated growth traits of the Murciano-Granadina goat across the levels of the considered fixed effects are presented in Table 3. The birth year and birth month of kids significantly affected all the studied growth traits ($P < 0.01$). The sex of kids significantly affected all the studied growth traits ($P < 0.01$). Male kids have significantly higher pre-weaning growth rates, Kleiber ratios and growth efficiency than female kids ($P < 0.01$). Furthermore, they were generally heavier than the females at birth and at weaning time. The birth type of Murciano-Granadina kids had a significant effect on all the studied growth traits ($P < 0.01$). The single-born Murciano-Granadina kids were superior to multiple births for all the studied growth traits. Dam age significantly affected on all the studied growth traits of the Murciano-Granadina kids ($P < 0.01$).

Genetic parameter estimates

Model comparisons

The results of model comparisons by using AIC (Table 4) revealed that the maternal effects influenced all the studied early growth traits in the Murciano-Granadina kids. Among the tested models, the best model of genetic analysis determined for BW, included direct additive, maternal additive, maternal permanent and litter

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Table 3. Least squares means (± S.E.) for the studied growth traits of the Murciano-Granadina goat breed

Effect	Traits									
	BW (kg)	*n*	ADG (g/d)	*n*	KR (× 1000)[a]	*n*	GE	*n*	WW (kg)	*n*
Sex	**	-	**	-	**	-	**	-	**	
Male	2.51 ± 0.013	7287	105.9 ± 0.63	3551	18.39 ± 0.092	3551	333 ± 2.7	3551	10.31 ± 0.042	3551
Female	2.31 ± 0.013	7756	95.6 ± 0.63	3750	17.05 ± 0.091	3750	314 ± 2.7	3750	9.96 ± 0.042	3750
Birth type	**	-	**	-	**	-	**	-	**	-
Single	2.49 ± 0.015	6747	101.2 ± 0.63	2980	17.95 ± 0.094	2980	337 ± 2.7	2980	10.18 ± 0.043	2980
Multiple births	2.33 ± 0.012	8296	100.7 ± 0.65	4321	16.85 ± 0.091	4321	311 ± 2.8	4321	10.10 ± 0.042	4321
Dam age (yr)	**	-	**	-	**	-	**	-	**	-
1	2.22 ± 0.011	3442	102.2 ± 0.79	1425	18.0 ± 0.12	1425	350 ± 3.4	1425	10.11 ± 0.053	1425
2	2.40 ± 0.011	4409	101.8 ± 0.72	2115	17.7 ± 0.11	2115	332 ± 3.1	2115	10.29 ± 0.048	2115
3	2.47 ± 0.012	3320	100.0 ± 0.75	1836	17.7 ± 0.11	1836	312 ± 3.2	1836	10.08 ± 0.050	1836
4	2.47 ± 0.013	2405	99.0 ± 0.82	1392	17.5 ± 0.12	1392	311 ± 3.5	1392	10.04 ± 0.055	1392
5	2.51 ± 0.014	1467	101 ± 1.1	533	17.7 ± 0.15	533	315 ± 4.5	533	10.19 ± 0.071	533
Birth month	**	-	**	-	**	-	**	-	**	-
Birth year	**	-	**	-	**	-	**	-	**	-
Age at weaning	-	-	-	-	-	-	-	-	0.03 ± 0.001**	-

BW, birth weight; WW, weaning weight; ADG, average daily gain from birth to weaning; KR, Kleiber ratio from birth to weaning; GE, growth efficiency from birth to weaning.
n, number of records.
[a]KR values are multiplied by 1000.

effects, without considering covariance between direct and maternal additive genetic effects (Model 8), while the best model detected for ADG, KR and GE included direct additive, maternal permanent and litter effects (Model 5). The model including direct additive and maternal additive genetic effects, ignoring covariance between these effects, was determined as the best model for WW (Model 3).

Univariate analyses

The estimates of variance components and genetic parameters for the studied early growth traits in the Murciano-Granadina goats under the best univariate model are given in Table 5. The estimated direct heritabilities for BW, ADG, KR, GE and WW were low, with values of 0.04, 0.07, 0.08, 0.05 and 0.07, respectively. In the present study, maternal additive genetic effects were only important for the genetic analysis of BW and WW. Maternal heritability estimates for BW and WW were 0.03 and 0.04, respectively. Except for WW, all the studied traits were affected by maternal permanent environmental and maternal temporary environmental (litter) effects. The ratios of maternal permanent environmental variance to phenotypic variance (pe^2) were 0.08, 0.04, 0.04 and 0.06 for BW, ADG, KR and GE, respectively. The ratios of maternal temporary environmental or litter variance to phenotypic variance (l^2) were 0.26, 0.17, 0.16 and 0.19 for BW, ADG, KR and GE, respectively.

Table 4. Akaike information criterion (AIC) values for the studied traits in the Murciano-Granadina goat breed under different models

Model	Traits				
	BW	ADG	KR	GE	WW
Model 1	−15 457	50 351	22 293	71 464	10 308
Model 2	−15 678	50 340	22 283	71 420	10 306
Model 3	−15 635	50 337	22 287	71 418	**10 296**
Model 4	−15 627	50 339	22 286	71 425	10 298
Model 5	−15 924	**50 318**	**22 242**	**71 381**	10 306
Model 6	−15 686	50 342	22 290	71 417	10 304
Model 7	−15 678	50 341	22 284	71 425	10 306
Model 8	**−15 930**	50 321	22 250	71 385	10 303
Model 9	−15 923	50 321	22 246	71 390	10 306

BW, birth weight; WW, weaning weight; ADG, average daily gain from birth to weaning; KR, Kleiber ratio from birth to weaning; GE, growth efficiency from birth to weaning.

Multivariate analyses

The estimates of genetic, phenotypic and environmental correlations among the studied growth traits of the Murciano-Granadina goat are shown in Table 6. The estimates of genetic correlations among the studied traits were positive and low to high in magnitude, which ranged from 0.11 for BW-KR to 0.91 for BW-GE. The phenotypic correlations ranged from 0.03 for KR-WW to 0.87 for ADG-KR. In the present study, the maternal genetic correlation estimate between BW and WW was obtained at 0.47. Maternal permanent environmental correlations were also positive and ranged from a low estimate of 0.08 for BW-KR to a high estimate of 0.82 for BW-GE. In the present study, correlations related to litter effects were positive and ranged from low (0.07 for BW-ADG) to high (0.92 for ADG-KR) estimates.

Discussion

The considered fixed effects were significant sources of variation for all the studied growth traits of Murciano-Granadina kids.

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Table 5. Estimates of variance components and genetic parameters for the studied early growth traits in the Murciano-Granadina goat breed under the best univariate model

Trait	The best univariate model	σ_e^2	σ_p^2	h_a^2	h_m^2	pe^2	l^2
BW	8	0.08 ± 0.002	0.14 ± 0.002	0.04 ± 0.012	0.03 ± 0.012	0.08 ± 0.013	0.26 ± 0.015
ADG	5	327 ± 9.0	451 ± 12.2	0.07 ± 0.018	-	0.04 ± 0.014	0.17 ± 0.027
KR	5	8.4 ± 0.31	11.6 ± 0.20	0.08 ± 0.019	-	0.04 ± 0.014	0.16 ± 0.027
GE	5	4704 ± 171.0	6690 ± 113.8	0.05 ± 0.016	-	0.06 ± 0.015	0.19 ± 0.026
WW	3	1.17 ± 0.028	1.33 ± 0.023	0.07 ± 0.020	0.04 ± 0.013	-	-

BW, birth weight; WW, weaning weight; ADG, average daily gain from birth to weaning; KR, Kleiber ratio from birth to weaning; GE, growth efficiency from birth to weaning.
σ_e^2: residual variance, σ_p^2: phenotypic variance, h_a^2: direct heritability,h_m^2: maternal heritability, pe^2: ratio of maternal permanent environmental variance to phenotypic variance, l^2: ratio of litter variance to phenotypic variance.

Table 6. The estimates of genetic, phenotypic and environmental correlations among the studied traits of the Murciano-Granadina goat breed

Trait 1	Trait 2	r_a	r_{pe}	r_l	r_e	r_p
BW	ADG	0.32 ± 0.061	0.12 ± 0.009	0.07 ± 0.011	0.07 ± 0.018	0.07 ± 0.008
BW	KR	0.11 ± 0.020	0.08 ± 0.028	0.19 ± 0.047	0.12 ± 0.017	0.13 ± 0.008
BW	GE	0.91 ± 0.033	0.82 ± 0.061	0.85 ± 0.032	0.70 ± 0.012	0.75 ± 0.009
BW	WW	0.21 ± 0.062	0.5 ± 0.15	0.36 ± 0.088	0.08 ± 0.021	0.12 ± 0.012
ADG	KR	0.75 ± 0.094	0.79 ± 0.098	0.92 ± 0.023	0.87 ± 0.014	0.87 ± 0.009
ADG	GE	0.76 ± 0.099	0.11 ± 0.041	0.19 ± 0.081	0.41 ± 0.023	0.38 ± 0.011
ADG	WW	0.6 ± 0.14	0.6 ± 0.13	0.17 ± 0.024	0.57 ± 0.018	0.51 ± 0.012
KR	GE	0.38 ± 0.081	0.27 ± 0.066	0.17 ± 0.057	0.12 ± 0.030	0.12 ± 0.008
KR	WW	0.23 ± 0.072	0.21 ± 0.088	0.2 ± 0.11	0.10 ± 0.028	0.03 ± 0.009
GE	WW	0.7 ± 0.11	0.3 ± 0.11	0.3 ± 0.10	0.65 ± 0.019	0.58 ± 0.013

BW, birth weight; WW, weaning weight; ADG, average daily gain from birth to weaning; KR, Kleiber ratio from birth to weaning; GE, growth efficiency from birth to weaning; r_a, direct genetic correlation; r_{pe}, maternal permanent environmental correlation; r_l, maternal temporary environmental (litter) correlation; r_e, residual correlation; r_p, phenotypic correlation.

Therefore, these effects should be included in the models used for the genetic evaluation of the Murciano-Granadina kids for early growth performance traits. The significant influences of these fixed effects on the growth traits of several goat breeds have been well documented (Baneh *et al*., 2012; Barazandeh *et al*., 2012; Mokhtari *et al*., 2019; Singh *et al*., 2022; Hosseinzadeh Shirzeyli *et al*., 2023). The significant effects of birth year and birth month of kids on the studied traits may be explained partly by variations in annual weather conditions and flock management practices during the period of study (Hosseinzadeh Shirzeyli *et al*., 2023; Wang *et al*., 2023). Sexual differences were found between the male and female Murciano-Granadina kids for the studied growth traits. The sexual-related differences in growth performance of kids may be the result of different physiological characteristics, and also different hormone types and hormone secretion, especially sexual hormones such as Oestrogen (Aguirre *et al*., 2016). The superiority of the single-born Murciano-Granadina kids over multiple births kids in early growth performance may be justified to some extent by the fact that the single-born kids can benefit more from the whole uterine and maternal environment than multiple births kids. Therefore, the kids with multiple births will receive less nutrition from the dam (Boujenane and Diallo, 2017). The effect of dam age on the studied traits may be ascribed to several factors such as the growth stage, higher mothering ability, reproductive performance and the higher milk yield of does at older ages (Hosseinzadeh Shirzeyli *et al*., 2023). Mothering ability may lead to a better uterus capacity and maternal behaviour of the dams.

The low estimates of direct heritability for the studied growth traits in the Murciano-Granadina breed in this study indicated that direct genetic selection for these traits may not result in significant genetic progress, due to the low levels of direct additive genetic variation. Such lack of genetic variability in pre-weaning growth traits has also been reported by Bangar *et al*. (2020) in the Jakhrana goat breed. Menezes *et al*. (2016) reported direct heritability estimates for BW, WW and ADG in Boer goats as 0.08, 0.23 and 0.31, respectively. These estimates were higher than the corresponding estimates in the present study. Higher direct heritability estimates of 0.22, 0.12 and 0.25 for BW, ADG and WW, respectively, were reported in Raeini Cashmere goats (Mohammadi *et al*., 2012). Mokhtari *et al*. (2019) reported direct heritability estimates of 0.08 and 0.07 for pre-weaning average daily gain and growth efficiency in Raeini Cashmere goats, which were in agreement with the corresponding estimated direct heritabilities of the Murciano-Granadina goat breed in the present study (0.07 for ADG and 0.05 for GE). They also reported a value of 0.19 for direct heritability of pre-weaning KR in Raeini Cashmere goat, which was higher than the estimated values for KR in the present study. There is limited information on genetic parameter estimates of growth efficiency-related traits of goat breeds in the literature. Direct heritability estimates of 0.07 and 0.06 for pre-weaning growth efficiency in Makooei (Ghafouri-Kesbi and Abbasi, 2019) and Baluchi (Ghafouri-Kesbi and Gholizadeh, 2017) sheep breeds were close to the direct heritability estimate of GE in the present study (0.05). Bangar *et al*. (2020) reported estimates of 0.09, 0.21, 0.17 and 0.06 for direct

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heritabilities of birth weight, three-month weight, pre-weaning average daily gain and pre-weaning Kleiber ratio in the Jakhrana goat breed, respectively. Estimates on genetic parameters for growth efficiency traits in goat breeds are limited.

As expected, maternal effects constitute sizeable parts of the phenotypic variations for all the studied growth traits of the Murciano-Granadina kids. Maternal effects increase sibling resemblance and, if not included in models used for genetic evaluation animals, may bias estimates of direct heritability upward (Singh *et al.*, 2022). In this study, maternal additive genetic effects were important for the genetic evaluation of the BW and WW of the Murciano-Granadina kids. Maternal permanent and also maternal temporary environmental effects were also important genetic evaluation of the Murciano-Granadina kids for all the studied traits except for WW. Therefore, it is recommended to account for the maternal effects and additive genetic and environmental factors for estimating genetic parameters of early growth traits in the Murciano-Granadina goat breed. The necessity of considering maternal additive genetic, maternal permanent and maternal temporary environmental effects for genetic evaluation of early growth traits in Markhoz goat remembered by Rashidi *et al.* (2011). In general, the influence of maternal effects on the growth traits has been well-documented in various goat breeds, including Naeini (Baneh *et al.*, 2012), Raeini Cashmere (Barazandeh *et al.*, 2012; Mohammadi *et al.*, 2012; Mokhtari *et al.*, 2019), Barbari goat (Singh *et al.*, 2022), Markhoz (Rashidi *et al.*, 2008; Hosseinzadeh Shirzeyli *et al.*, 2023), Jamunapari (Dige *et al.*, 2021) and Inner Mongolia White Arbas Cashmere (Wang *et al.*, 2023).

Mohammadi *et al.* (2012) estimated maternal heritabilities of 0.17 and 0.07 for BW and WW, in Raeini Cashmere goats, respectively. Dige *et al.* (2021) reported the maternal heritability of BW and WW in Jamunapari goats to be 0.11 and 0.26, respectively. In a recently published study, maternal heritability estimates of BW and WW in inner Mongolia white Arbas Cashmere goats were reported at 0.0143 and 0.0246, respectively (Wang *et al.*, 2023), which were similar to the corresponding estimated values in the present study. In this study, low maternal heritability but statistically significant estimates were obtained for BW (0.03) and WW (0.04) of the Murciano-Granadina kids. Although maternal additive genetic effects explained low proportions of the phenotypic variances for BW and WW in the Murciano-Granadina goat breed, their effects on phenotypic variance were statistically significant, and excluding them from models used for genetic evaluation of these traits may resulted in upward biased direct heritability estimates. Erdogan Atac *et al.* (2023) estimated genetic parameters for direct and maternal effects on pre-weaning growth traits in Turkish Saanen kids and reported that maternal effects perform a significant role in the expression of pre-weaning growth traits in this breed and including them in models resulted in more realistic variance components.

Maternal permanent environmental effects refer to environmental factors that consistently impact the performance of dams across multiple kiddings. The maternal permanent environmental effects on birth weight are mainly characterized by the uterine capacity of the dam, feeding level at late gestation and maternal behaviour (Ghafouri-Kesbi and Eskandarinasab, 2008). In the present study, maternal permanent environmental effects explained low proportions of the phenotypic variances for BW (8%), ADG (4%), KR (4%) and GE (6%) in the Murciano-Granadina goat breed, but their effects on phenotypic variance were statistically significant and including them in models used for genetic evaluation of these traits is necessary. Furthermore, improving the feeding of does at late stage of gestation is of great important for more accurate genetic evaluation of the Murciano-Granadina kids for BW, ADG, KR and GE. Snyman *et al.* (1995) showed that excluding the maternal permanent environmental effects could cause maternal heritability to be overestimated.

Snyman *et al.* (1995) demonstrated that eliminating the maternal permanent environmental effects could result in maternal heritability being over-estimated. Baneh *et al.* (2012) reported a pe^2 estimate of 0.16 for ADG in the Naeini goat breed, which was higher than the estimated value for ADG of the Murciano-Granadina goat breed in the present study. Singh *et al.* (2022) reported estimates of 0.10 and 0.09 for pe^2 of pre-weaning average daily gain and Kleiber ration in Barbari goats, respectively. Mohammadi *et al.* (2012) estimated a pe^2 value of 0.05 for pre-weaning average daily gain in Raeini Cashmere goat, which is in agreement with that obtained for ADG in the present study. Hosseinzadeh Shirzeyli *et al.* (2023) estimated pe^2 of 0.09 for BW in Markhoz goat, which is in agreement with the corresponding estimated value for BW in the present study. Bangar *et al.* (2020) estimated pe^2 of 0.18 for BW in the Jakhrana goat breed, which was higher than the corresponding estimated value in the present study. In a recently published study, Wang *et al.* (2023) estimated low magnitude values of 0.0567, 0.0246 and 0.0314 for pe^2 of BW, pre-weaning average daily gain and pre-weaning KR in inner Mongolia white Arbas cashmere goats, respectively.

In all the examined traits, the maternal temporary environmental effects or litter effects contributed significantly more to the phenotypic variances than other known random sources of variation, such as direct additive genetic, maternal additive genetic (for BW and WW) and maternal permanent environmental effects (for BW, ADG, KR and GE). The maternal temporary environmental or litter effect refers to this fact that kids from the same litter are phenotypically more similar than kids from different litters. Litter effects together with maternal permanent environmental effects allow for greater resemblance between full sibs from the same litter *v.* similarly related individuals from different litters (Ghafouri-Kesbi *et al.*, 2022). Similarly, Menezes *et al.* (2016) obtained estimates of 0.32 and 0.15 for l^2 of BW and ADG in the Boer goat breed, respectively. Rout *et al.* (2018) estimated values of 0.39, 0.29 and 0.29 for l^2 of birth weight, average daily gain from birth to three-month body weight and three-month body weight in Jamunapari goats breed, respectively. The estimates of l^2 for BW and pre-weaning KR of Markhoz goat were obtained at 0.46 and 0.16, respectively (Rashidi *et al.*, 2011). Hagger (1998) studied the influence of litter effects on the early growth rate of two Switzerland sheep breeds and showed that the importance of the litter effects was more pronounced than other direct and maternal effects.

The observed positive genetic and phenotypic correlations suggest that selecting any of the studied growth traits in the Murciano-Granadina goat breed would not result in unfavourable genetic or phenotypic changes in the other traits. In other words, all the studied traits can be improved simultaneously following selection for any of these traits. Positive genetic correlations among the studied traits of the Murciano-Granadina goat breed in the present study represent some degree of pleiotropic effects on these traits, which is more pronounced for BW and GE.

Baneh *et al.* (2012) estimated values of 0.49, 0.61 and 0.94 for genetic correlations of BW-ADG, BW-WW and ADG-WW in the Naeini goat breed, respectively. They reported phenotypic correlation estimates of 0.03, 0.24 and 0.95 for BW-ADG, BW-WW and

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ADG-WW in the Naeini goat breed, respectively. These estimates in the Naeini goat breed were higher than the corresponding genetic and phenotypic correlation estimates in the present study. Rashidi *et al.* (2011) reported positive and low to high phenotypic and genetic correlation estimates among the pre-weaning growth traits in Markhoz goats including BW, WW, ADG and KR; varied from 0.23 (BW-KR) to 0.98 (WW-ADG) for genetic correlations and from 0.07 (BW-KR) to 0.97 (WW-ADG) for phenotypic ones. These estimated values in the Markhoz goat were generally higher than those estimated in the present study. Wang *et al.* (2023) reported direct genetic correlations of 0.012, −0.002 and −0.026 for BW-WW, BW-ADG and BW-KR in inner Mongolia white Arbas Cashmere goat, respectively. They reported phenotypic correlations of 0.062, −0.098 and −0.294 for BW-WW, BW-ADG and BW-KR in the inner Mongolia white Arbas Cashmere goat breed, respectively (Wang *et al.*, 2023). Estimated values for the phenotypic and genetic correlations for BW-ADG and BW-KR in the present study were positive, but the corresponding estimated values by Wang *et al.* (2023) in inner Mongolia white Arbas Cashmere goat breed were negative. These differences may be explained partly by differences in breed and data structure.

The variations in maternal permanent environmental effects may be explained by the differences in intrauterine conditions during pregnancy, nutrient availability during pregnancy and lactation, maternal behaviour and the mothering ability of the dam (Wang *et al.*, 2023). Maternal permanent environmental correlations among pre-weaning growth traits in inner Mongolia white Arbas Cashmere goat breed ranged from −0.289 for BW-KR to 0.90 for WW-ADG (Wang *et al.*, 2023). Maternal genetic correlations between BW and WW in Markhoz goat (Rashidi *et al.*, 2008), Jamunapari goat (Dige *et al.*, 2021) and inner Mongolia white Arbas Cashmere goat (Wang *et al.*, 2023) breeds were reported as 0.43, 0.77 and 0.388, respectively.

Conclusion

The results of this study highlight the significant impact of environmental effects on the early growth performance of Murciano-Granadina kids. Furthermore, maternal effects had important influences on the early growth traits of the Murciano-Granadina goat breed. Therefore, accurate identification and recording of dams identities are necessary. Low estimates of direct heritability for the examined traits suggest limited genetic variability within the Murciano-Granadina goat breed population. As a result, genetic progress for these traits can not be achieved rapidly through mass selection. In addition to direct genetic effects, maternal genetic effects (for BW and WW), maternal permanent environmental effects and litter effects (for BW, ADG, KR and GE) were shown to be important for the genetic evaluation of the Murciano-Granadina kids. These effects should be included in the genetic analysis models for estimating more accurate breeding values of the selection candidates. In other words, the breeding programme should consider both improvement in environmental effects and maternal performance of dams into account for developing an efficient selection process in this breed. The moderate-to-high estimates of genetic correlation among the studied traits indicate that selection for any of these traits could lead to improvements in the other traits and could be useful for selecting kids at an early age.

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