



## Non-genetic Effects and Genetic Parameters Estimation on Growth Traits of Indonesian Etawah Grade Goats

A. R. Nugroho<sup>1,3</sup>, C. Sumantri<sup>2</sup>, A. Sutanto<sup>3</sup>, M. F. Ulum<sup>4</sup>, & A. Gunawan<sup>2,\*</sup>

<sup>1</sup>Graduate School of Animal Production and Technology, Faculty of Animal Science, IPB University, Indonesia

<sup>2</sup>Department of Animal Production and Technology, Faculty of Animal Science, IPB University, Indonesia

<sup>3</sup>National Breeding Station of Pelaihari, Ministry of Agriculture, South Borneo, Indonesia

<sup>4</sup>Division of Reproduction and Obstetrics, School of Veterinary Medicine and Biomedical Sciences, IPB University, Indonesia

\*Corresponding author: [agunawan@apps.ipb.ac.id](mailto:agunawan@apps.ipb.ac.id)

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### ABSTRACT

Growth traits are important determinants of the efficiency and productivity of goat production systems. The Etawah Grade (EG) goat is a local Indonesian breed that is used for both milk and meat production. This study aimed to analyze the influence of non-genetic factors, estimate genetic parameters, and assess long-term genetic progress in growth traits of the EG goat at different ages. A total of 17,783 body weight records from 523 sires and 4342 dams were used to analyze non-genetic effects and estimate genetic parameters for growth traits in EG goats. The effect of non-genetic factors (sex, parity, season, year, and type of birth) on growth traits (body weight and average daily gain) was analyzed using a general linear model (GLM). Heritability and genetic trend were estimated using restricted maximum likelihood (REML) in the BreedR package from the R program. The results of this study showed that sex, parity, season, year, and type of birth had significant effects ( $p < 0.01$ ) on almost all growth traits. The heritability of growth traits was classified as low to moderate heritability (0.085-0.352). The genetic correlation in this study between all traits ranged from weakly positive to strongly positive (0.10-0.88). The estimated genetic trend in this study, based on estimated breeding values (EBV), was increased for all growth traits except 8MW and ADG8. These findings could provide a comprehensive longitudinal evaluation of growth performance and genetic progress in EG goats, offering practical insights to optimize selection strategies and improve breeding program effectiveness.

**Keywords:** *body weight; etawah grade goat; genetic parameters; non-genetic factor; selection*

### INTRODUCTION

Goats represent a strategic commodity within Indonesia's agribusiness sector, driven by the country's rapidly growing population. According to the Directorate General of Livestock and Animal Health Services (2024), the goat population in Indonesia increased from 14,374,014 in 2023 to 15,710,055 in 2024. Goats play a significant role in fulfilling the nutritional needs of humans, particularly in rural areas (Gunawan *et al.*, 2018). Goats are widely distributed across the country, with almost 99% of goats farmed by smallholders in small-scale production, typically with 2 to 8 animals per farm (Sujarwanta *et al.*, 2024). Smallholders favor goats due to their ease of management, consistent market demand, function as a financial reserve, and frequent use in religious or cultural ceremonies. Most farmers prefer to raise local breeds, as these animals are well-adapted to Indonesia's climate and environmental conditions (Rusdin *et al.* 2020; Khasanah *et al.*, 2016)

The Etawah Grade (EG) goat is an indigenous Indonesian breed, classified as a dual-purpose breed that is used for both milk and meat production (Figure 1). The EG goat is originated from crossbreeding between the Jamunapari goat from India with local Indonesian goats, developed over a long period, since the Dutch colonial era. The Indonesian government has officially recognized the EG goat as a local goat breed through Ministerial Decree of Agriculture No. 695/Kpts/PD.410/2/2013. Despite this recognition, the potential of the EG goats has not been fully realized, resulting in lower production performance compared to introduced goat breeds. The development of EG goats can be achieved through breeding programs that improve their productivity, genetic quality, and economic value. Effective implementation of breeding programs requires comprehensive recording systems and complete information on various factors influencing production traits (Resti *et al.*, 2024). Estimating genetic parameters, including heritability, genetic correlation, and Estimated Breeding Value (EBV), is an essential step in selecting



Figure 1. Etawah Grade (EG) goat

superior breeding stock for traits with high economic value.

Growth traits are important production traits in goats, significantly influencing both survival and economic value. These traits are essential for assessing the potential for meat production and reproductive performance. Growth traits are determined by both genetic and non-genetic factors, including birth year, climate, birth type, sex, and parity (Ofori & Hagan, 2020). Non-genetic factors may mask an individual’s true genetic potential, as animal performance results from the interaction between genetic and environmental influences (Mamutse *et al.*, 2023). A better understanding of non-genetic effects on body weight traits is necessary to optimize management and improve the accuracy of estimating genetic parameters in EG goats.

Previous studies on non-genetic effects and genetic parameters have focused on several goat breeds, including Jamunapari goat (Dige *et al.*, 2022), Assam Hill goat (Sarma *et al.*, 2019), and Sirohi goat (Dudhe *et al.*, 2015). For Indonesian local goats, genetic parameter estimation has been reported for the Saperaga goat (Anggraeni *et al.*, 2020) and the EG goat (Hasan *et al.*, 2014). However, there is limited information regarding non-genetic effects and on genetic parameters estimation for growth traits in the Indonesian local goat, particularly the EG goat. Incorporating non-genetic

factors as fixed effects in the model and using a large sample size are essential for improving the accuracy of genetic parameter estimation (Atoui *et al.*, 2017). The present study aims to analyze the influence of non-genetic factors, estimate genetic parameters, and assess long-term genetic progress for growth traits of the EG goat at different ages.

## MATERIALS AND METHODS

### Data Collection and Definition of Factors

All procedures in this study were approved by the Animal Ethics Commission of IPB University (Approval No. 349–2025 IPB). The dataset comprised 17,783 body weight records, including birth weight (BW), weaning weight (WW), 6-months Weight (6MW), 8-months Weight (8MW), and 12-months Weight (12MW) (Table 1). Data were obtained from the production records of EG goats at the National Breeding Station of Pelaihari from 2015 to 2024. The average daily gain (ADG) was calculated using the following equation:

$$ADG3 = (WW - BW) / D$$

$$ADG6 = (6MW - WW) / D$$

$$ADG8 = (8MW - 6MW) / D$$

$$ADG12 = (12MW - 8MW) / D$$

ADG3 is the value of average daily gain from 0 to 3 months of age, ADG6 denotes the average daily gain from 3 to 6 months, ADG8 refers to average daily gain from 6 to 8 months, ADG12 denotes the average daily gain from 8 to 12 months, and D refers to the number of days between the second and first weighing.

The body weight and average daily gain at specific ages were analyzed to evaluate the effects of various non-genetic factors, which were categorized into levels as follows:

1. The season of production was classified into two categories: dry season (April-September) and rainy season (October-March).
2. Sex was classified into two categories: male and female.
3. Parity was defined as the kidding frequency of each doe, which was classified into five levels from 1 to ≥5.

Table 1. Data structure and descriptive statistics of Etawah Grade goat body weight

Category	Growth traits at different ages								
	BW (kg)	WW (kg)	6MW (kg)	8MW (kg)	12MW (kg)	ADG3 (kg day <sup>-1</sup> )	ADG6 (kg day <sup>-1</sup> )	ADG8 (kg day <sup>-1</sup> )	AD12 (kg day <sup>-1</sup> )
No. of animals	6843	4014	3669	1550	1707	4014	3626	1194	1704
No. of animals with pedigree record	6843	4014	3669	1550	1707	4014	3626	1194	1704
No. of sire	119	110	105	92	97	110	105	90	88
No. of dam	1057	952	939	710	684	952	928	625	684
Average progeny of sire	58	36	35	16	18	36	35	13	18
Average progeny of dam	6	4	4	2	2	4	4	2	2
Generations	4	4	4	4	4	4	4	4	4
Mean	3.491	14.754	21.223	26.062	31.062	0.124	0.090	0.091	0.068
SE	0.008	0.060	0.085	0.151	0.167	0.001	0.001	0.002	0.001
CV (%)	18.476	25.602	24.138	22.758	22.120	32.348	49.560	60.111	55.691

Note: BW=Birth weight, WW=Weaning weight, 6MW= 6-months weight, 8MW=8-months weight, 12MW=12-months weight, ADG3=Average daily gain from 0 to 3-months old, ADG6=Average daily gain from 3 to 6-months old, ADG8=Average daily gain from 6 to 8-months old, ADG12=Average daily gain from 8 to 12-months old SE= Standard error of mean, and CV= coefficient of variance.

4. The type of birth was defined as the number of kids born, which was classified into four categories: single, twin, triplet, and quadruplet.
5. Year of birth was classified into ten categories: from 2015 to 2024.

### Statistical Model

Descriptive statistics, including mean, standard deviation, and standard error of mean, were calculated for all traits in the dataset. The effects of non-genetic factors (sex, parity, season, year, and type of birth) on growth traits at different ages were analyzed using a General Linear Model (GLM). Statistical analysis was conducted using the R program (version 4.5.1). Significant differences ( $p < 0.05$ ) among the results were further analyzed using Duncan's Multiple Range Test (DMRT). A statistical model of the GLM for the trait is described below:

$$Y_{ijklm} = \mu + S_i + P_j + SoB_k + YoB_l + ToB_m + \epsilon_{ijklm}$$

Where  $Y_{ijklm}$  is the value of the body weight in the different ages (BW, WW, 6MW, 8MW, 12MW, ADG3, ADG6, ADG8, or ADG12),  $\mu$  refers to the overall mean,  $S_i$  refers to the fixed effect of sex,  $P_j$  is the fixed effect of parity,  $SoB_k$  represent fixed the effect of season of birth,  $YoB_l$  is the fixed effect of year of birth,  $ToB_m$  refers to the fixed effect of type of birth, and  $\epsilon_{ijklm}$  is the random residual effect.

### Estimating Genetic Parameters

Genetic parameters estimation was conducted by evaluating heritability, phenotypic correlations, and genetic correlations. Heritability is a measure of the degree to which offspring resemble their parents in performance for a trait. Phenotypic correlation measures the strength of the relationship between performance (phenotypic value) in one trait and performance in another trait. Genetic correlation measures the strength of the relationship between breeding values for one trait and breeding values for another trait. The characteristics of the pedigree and data structure for all growth traits are listed in Table 1. All animals included in the analysis had complete pedigree records, reflecting a high level of pedigree completeness. The dataset included a substantial number of records per trait, and the average number of progenies per sire or dam was sufficient to estimate genetic parameters. The relatively high number of progenies per sire indicates a strong contribution of sires to the population structure, which is beneficial for accurate genetic evaluation.

The estimation of (co)variance components was conducted using the model with Restricted Maximum Likelihood (REML), applying the BreedR package from the R program (version 4.5.1). The mixed-model equation for estimating genetic parameters of production traits was referred to Walsh & Lynch (2018):

$$Y = X\beta + Za + e$$

Where  $Y$  is the vector of observations (BW, WW, 6MW, 8MW, 12MW, ADG3, ADG6, ADG8, or ADG12),  $\beta$  is the

vector of the fixed effect (sex, parity, season, year, and type of birth),  $a$  is the vector related to random additive genetic effect of the animal,  $X$  and  $Z$  are the incidence matrices relating to observations of the factors in the model, and  $e$  is the residual effect.

The heritability for each trait was calculated based on Alam *et al.* (2021), while phenotypic and genetic correlation were calculated based on Bourdon (2014):

Heritability:

$$h^2 = \frac{\sigma_a^2}{\sigma_p^2} \text{ where, } \sigma_p^2 = \sigma_a^2 + \sigma_e^2$$

Where  $\sigma_a^2$  refers to the additive genetic variance of the animal,  $\sigma_p^2$  refers to the phenotypic variance, and  $\sigma_e^2$  refers to residual variance.

Phenotypic correlation:

$$r_p = \frac{COV_p(XY)}{\sigma_{px} \sigma_{py}}$$

Genetic correlation:

$$r_g = \frac{COV_g(XY)}{\sigma_{gx} \sigma_{gy}}$$

$COV_p(XY)$  and  $COV_g(XY)$  refer to the phenotypic and genetic covariances between the two traits. Meanwhile,  $\sigma_{px}$  and  $\sigma_{gx}$  refer to the phenotypic and additive genetic standard deviations of the first trait, whereas  $\sigma_{py}$  and  $\sigma_{gy}$  refer to the phenotypic and additive genetic standard deviations of the second trait.

The genetic trend was estimated to evaluate the genetic progress achieved during the years of observation. Genetic trend evaluation was conducted by creating a trend plot of EBV means for each trait as a function of birth year. The breeding values of individual animals were estimated using BLUP in the R program (version 4.5.1) using the BreedR package.

## RESULTS

### Non-Genetic Effect

The descriptive statistic showed the value of mean and standard error of BW, WW, 6MW, 8MW, and 12MW of Etawah Grade goat were  $3.491 \pm 0.008$  kg (CV=18.476%);  $14.754 \pm 0.060$  kg (CV=25.602%);  $21.223 \pm 0.085$  kg (CV=24.138%);  $26.062 \pm 0.151$  kg (CV=22.758%); and  $31.062 \pm 0.167$  kg (CV=22.120%), respectively (Table 1). The overall value of mean and standard error of ADG3, ADG6, ADG8, and ADG12 of EG goat were  $0.124 \pm 0.001$  kg day<sup>-1</sup> (CV=32.348%);  $0.090 \pm 0.001$  kg day<sup>-1</sup> (CV=49.560%);  $0.091 \pm 0.002$  kg day<sup>-1</sup> (CV=60.111%); and  $0.068 \pm 0.001$  kg day<sup>-1</sup> (CV=55.691%), respectively (Table 1). The result of this study showed that sex, parity, season, year, and type of birth had a highly significant effect ( $p < 0.01$ ) on all body weight traits in this study, except for season of birth, which was not significant ( $p > 0.05$ ) for 8MW (Table 2). For ADG traits, sex, parity, season, year, and type of birth had a significant effect ( $p < 0.05$ ) on ADG3 and ADG6 (Table 3).

Table 2. Body weight (kg) of Etawah Grade (EG) goat at a specific age (Mean ± SE)

Factor	Body weight at a specific age										
	n	BW	n	WW	n	6MW	n	8MW	n	12MW	
		**		**		**		**		**	
Season	Rainy	3395	3.51±0.011 <sup>a</sup>	2004	15.09±0.069 <sup>a</sup>	1808	21.78±0.095 <sup>a</sup>	680	25.77±0.160 <sup>b</sup>	884	30.54±0.179 <sup>b</sup>
	Dry	3448	3.47±0.011 <sup>b</sup>	2010	14.41±0.069 <sup>b</sup>	1861	20.99±0.093 <sup>b</sup>	835	26.36±0.178 <sup>a</sup>	732	31.47±0.163 <sup>a</sup>
		**		**		**		**		**	
Sex	Male	3342	3.63±0.009 <sup>a</sup>	2044	15.46±0.070 <sup>a</sup>	1867	22.55±0.095 <sup>a</sup>	855	27.66±0.180 <sup>a</sup>	481	32.72±0.220 <sup>a</sup>
	Female	3501	3.35±0.009 <sup>b</sup>	2078	14.06±0.069 <sup>b</sup>	1927	19.96±0.093 <sup>b</sup>	660	24.78±0.159 <sup>b</sup>	1135	30.35±0.143 <sup>b</sup>
		**		**		**		**		**	
Birth type	Single	1176	3.89±0.019 <sup>a</sup>	756	16.19±0.112 <sup>a</sup>	672	22.31±0.156 <sup>a</sup>	313	26.92±0.262 <sup>a</sup>	385	31.16±0.246 <sup>a</sup>
	Twin	4174	3.55±0.009 <sup>b</sup>	2473	14.50±0.062 <sup>b</sup>	2239	20.95±0.086 <sup>b</sup>	911	25.74±0.153 <sup>a</sup>	1001	31.87±0.152 <sup>a</sup>
	Triplet	1393	3.02±0.013 <sup>c</sup>	749	14.21±0.113 <sup>b</sup>	726	21.16±0.150 <sup>b</sup>	278	26.10±0.278 <sup>a</sup>	212	31.99±0.332 <sup>a</sup>
	Quadruplet	100	2.60±0.042 <sup>d</sup>	36	13.05±0.517 <sup>c</sup>	32	18.74±0.713 <sup>c</sup>	13	23.14±1.2857 <sup>b</sup>	18	27.86±1.139 <sup>b</sup>
		**		**		**		**		**	
Parity	1	1162	3.46±0.016 <sup>b</sup>	655	15.35±0.121 <sup>a</sup>	660	21.70±0.157 <sup>a</sup>	323	26.59±0.265 <sup>a</sup>	293	31.88±0.281 <sup>a</sup>
	2	1466	3.52±0.014 <sup>a</sup>	893	15.09±0.104 <sup>ab</sup>	802	21.31±0.142 <sup>ab</sup>	339	26.21±0.255 <sup>a</sup>	365	30.93±0.251 <sup>bc</sup>
	3	1382	3.53±0.014 <sup>a</sup>	804	14.82±0.109 <sup>b</sup>	723	21.46±0.150 <sup>a</sup>	272	26.31±0.282 <sup>a</sup>	379	30.92±0.247 <sup>bc</sup>
	4	1174	3.45±0.016 <sup>b</sup>	687	14.42±0.118 <sup>c</sup>	652	20.74±0.158 <sup>c</sup>	241	25.00±0.300 <sup>b</sup>	312	31.29±0.272 <sup>ab</sup>
	≥5	1659	3.48±0.013 <sup>b</sup>	975	14.22±0.100 <sup>c</sup>	832	20.95±0.140 <sup>bc</sup>	375	25.85±0.240 <sup>a</sup>	358	30.49±0.253 <sup>c</sup>
		**		**		**		**		**	
Year	2015	262	3.56±0.033 <sup>a</sup>	141	13.14±0.261 <sup>e</sup>	131	16.86±0.352 <sup>e</sup>	27	19.87±0.892 <sup>ef</sup>	119	27.00±0.443 <sup>d</sup>
	2016	325	3.48±0.030 <sup>bc</sup>	187	13.26±0.227 <sup>e</sup>	221	19.42±0.271 <sup>d</sup>	30	20.62±0.846 <sup>e</sup>	157	30.89±0.386 <sup>e</sup>
	2017	528	3.43±0.023 <sup>cd</sup>	382	12.82±0.159 <sup>e</sup>	202	16.01±0.283 <sup>f</sup>	96	18.85±0.473 <sup>fg</sup>	243	25.43±0.310 <sup>de</sup>
	2018	534	3.59±0.023 <sup>a</sup>	356	11.71±0.164 <sup>f</sup>	227	14.93±0.268 <sup>g</sup>	48	17.87±0.669 <sup>g</sup>	162	24.12±0.380 <sup>e</sup>
	2019	539	3.37±0.023 <sup>d</sup>	454	14.68±0.145 <sup>c</sup>	363	21.67±0.211 <sup>b</sup>	153	24.22±0.375 <sup>d</sup>	223	31.24±0.324 <sup>e</sup>
	2020	647	3.59±0.021 <sup>a</sup>	353	14.69±0.165 <sup>c</sup>	374	20.08±0.208 <sup>c</sup>	211	25.31±0.319 <sup>cd</sup>	99	32.57±0.486 <sup>c</sup>
	2021	873	3.54±0.018 <sup>ab</sup>	348	17.37±0.166 <sup>a</sup>	498	23.69±0.181 <sup>a</sup>	251	28.51±0.292 <sup>a</sup>	206	32.90±0.337 <sup>c</sup>
	2022	1094	3.46±0.016 <sup>c</sup>	607	15.48±0.126 <sup>b</sup>	642	22.07±0.159 <sup>b</sup>	261	27.31±0.287 <sup>ab</sup>	223	35.55±0.323 <sup>b</sup>
	2023	978	3.48±0.017 <sup>bc</sup>	672	16.96±0.119 <sup>a</sup>	639	24.34±0.160 <sup>a</sup>	322	28.77±0.258 <sup>a</sup>	177	39.04±0.363 <sup>a</sup>
	2024	1063	3.46±0.016 <sup>c</sup>	514	13.87±0.137 <sup>d</sup>	372	21.96±0.209 <sup>c</sup>	116	26.04±0.430 <sup>bc</sup>	7	32.20±1.826 <sup>c</sup>

Note: BW=Birth weight, WW=Weaning weight, 6MW= 6-months weight, 8MW=8-months weight, 12MW=12-months weight. Means in the same column with different superscript differ significantly (\* = p<0.05) or (\*\* = p<0.01).

ADG8 was only affected (p>0.05) by sex, year, and type of birth. ADG12 in this study was affected (p>0.05) by sex, season, and year of birth.

### Estimated Heritability

The variance components for all traits were estimated by assessing the effects of sex, parity, season, year, and birth type. Among all body weights, BW showed the lowest estimated additive genetic value (0.100). The estimated additive genetic variance increased with age, with values of 3.219 for WW, 7.439 for 6MW, 6.893 for 8MW, and 7.661 for 12MW. In contrast, average daily gain traits showed very low additive genetic variance, ranging from 0.0001 to 0.0004. The estimated phenotypic variance of body weight increased continuously with advancing age of the animals, showing a pattern similar to that of additive genetic variance. However, the phenotypic variance of average daily gain traits did not follow this pattern, with the highest value observed at ADG8 (0.0024) and the lowest at ADG12 (0.0011). The heritability of BW, WW, 6MW, 8MW, and 12MW were estimated to be 0.314±0.028; 0.265±0.034; 0.352±0.038; 0.273±0.054; and 0.254±0.052, respectively (Table 3). The heritability estimates for ADG3, ADG6, ADG8, and ADG12 in this study were 0.254±0.034; 0.135±0.029; 0.161±0.053; and 0.085±0.034, respectively (Table 3).

### Phenotypic and Genetic Correlation

All traits evaluated in this study showed positive phenotypic and genetic correlation, which ranged from weak to strong. The phenotypic correlation in this study ranged from 0.14 to 0.87, while the genetic correlations ranged from 0.10 to 0.88 (Figure 2). BW showed weak phenotypic and genetic correlations with other traits, with phenotypic correlation coefficients ranging from 0.14 to 0.25 and genetic correlation coefficients ranging from 0.10 to 0.18. Both phenotypic and genetic correlations increased with the advancing age of the animals. The WW, 6MW, 8MW, and 12MW had strong, positive phenotypic correlations (0.54-0.92) and genetic correlations (0.56-0.88). The strongest correlation was observed between 6MW and 8MW, with a phenotypic correlation of 0.92 and a genetic correlation of 0.88.

### Estimated Genetic Trend

The estimated genetic trend in this study, calculated using Estimated Breeding Values (EBV), indicated increased BW, WW, 6MW, and 12MW by 0.006; 0.048; 0.044; and 0.144 kg year<sup>-1</sup>, respectively, while 8MW declined by -0.006 kg year<sup>-1</sup> (Table 5 and Figure 3). Significant genetic trends (p<0.01) were observed for all body weight traits, except for 8MW, which showed a non-significant genetic trend (p>0.05). The genetic trend

Table 3. Average daily gain (kg day<sup>-1</sup>) of Etawah Grade (EG) goat at a specific age (Mean ± SE)

Factors		Average daily gain at a specific age							
		n	ADG3 **	n	ADG6 **	n	ADG8 **	n	ADG12 **
Season	Rainy	2004	0.128±0.001 <sup>a</sup>	1787	0.094±0.069 <sup>a</sup>	673	0.090±0.002 <sup>b</sup>	891	0.64±0.001 <sup>a</sup>
	Dry	2010	0.120±0.001 <sup>b</sup>	1839	0.087±0.069 <sup>b</sup>	521	0.091±0.002 <sup>a</sup>	505	0.078±0.001 <sup>b</sup>
Sex	Male	1981	0.130±0.001 <sup>a</sup>	1781	0.100±0.001 <sup>a</sup>	518	0.099±0.002 <sup>a</sup>	855	27.66±0.180 <sup>a</sup>
	Female	2033	0.118±0.001 <sup>b</sup>	1845	0.081±0.001 <sup>b</sup>	676	0.085±0.002 <sup>b</sup>	660	24.78±0.159 <sup>b</sup>
Birth type	Single	756	0.135±0.001 <sup>a</sup>	669	0.102±0.002 <sup>a</sup>	248	0.090±0.003 <sup>b</sup>	385	0.066±0.002
	Twin	2473	0.121±0.001 <sup>b</sup>	2211	0.088±0.008 <sup>b</sup>	722	0.090±0.002 <sup>b</sup>	1089	0.068±0.001
	Triplet	749	0.124±0.001 <sup>b</sup>	714	0.088±0.001 <sup>b</sup>	216	0.090±0.003 <sup>b</sup>	212	0.070±0.002
	Quadruplet	36	0.115±0.006 <sup>b</sup>	32	0.66±0.007 <sup>c</sup>	8	0.114±0.017 <sup>a</sup>	18	0.068±0.008
Parity	1	655	0.131±0.001 <sup>a</sup>	656	0.093±0.002 <sup>a</sup>	239	0.090±0.003	292	0.066±0.002
	2	893	0.128±0.001 <sup>b</sup>	789	0.093±0.001 <sup>a</sup>	248	0.097±0.003	364	0.066±0.002
	3	804	0.124±0.001 <sup>c</sup>	714	0.091±0.001 <sup>ab</sup>	202	0.089±0.003	378	0.070±0.002
	4	687	0.121±0.001 <sup>d</sup>	647	0.088±0.002 <sup>b</sup>	192	0.084±0.004	312	0.070±0.002
	≥5	975	0.119±0.001 <sup>d</sup>	820	0.087±0.001 <sup>b</sup>	313	0.090±0.002	358	0.067±0.002
Year	2015	141	0.105±0.003 <sup>e</sup>	130	0.065±0.003 <sup>e</sup>	25	0.049±0.010 <sup>d</sup>	119	0.060±0.003 <sup>b</sup>
	2016	187	0.108±0.002 <sup>e</sup>	221	0.080±0.003 <sup>d</sup>	29	0.047±0.009 <sup>d</sup>	157	0.072±0.003 <sup>b</sup>
	2017	382	0.104±0.001 <sup>e</sup>	198	0.057±0.003 <sup>f</sup>	76	0.042±0.00 <sup>d</sup>	243	0.045±0.002 <sup>c</sup>
	2018	356	0.090±0.002 <sup>f</sup>	224	0.055±0.003 <sup>f</sup>	42	0.038±0.008 <sup>d</sup>	162	0.043±0.002 <sup>c</sup>
	2019	454	0.125±0.002 <sup>c</sup>	362	0.092±0.002 <sup>bc</sup>	134	0.080±0.004 <sup>c</sup>	272	0.068±0.002 <sup>b</sup>
	2020	353	0.123±0.002 <sup>c</sup>	371	0.086±0.002 <sup>cd</sup>	201	0.091±0.003 <sup>bc</sup>	141	0.073±0.003 <sup>b</sup>
	2021	348	0.152±0.002 <sup>a</sup>	492	0.104±0.002 <sup>a</sup>	192	0.111±0.004 <sup>a</sup>	204	0.069±0.002 <sup>b</sup>
	2022	607	0.132±0.001 <sup>b</sup>	636	0.095±0.002 <sup>b</sup>	192	0.100±0.004 <sup>ab</sup>	222	0.086±0.002 <sup>a</sup>
	2023	672	0.148±0.001 <sup>a</sup>	629	0.110±0.002 <sup>a</sup>	227	0.107±0.003 <sup>ab</sup>	177	0.095±0.002 <sup>a</sup>
	2024	514	0.115±0.001 <sup>d</sup>	363	0.087±0.002 <sup>cd</sup>	76	0.092±0.006 <sup>bc</sup>	7	0.042±0.013 <sup>c</sup>

Note: ADG3=Average daily gain from 0 to 3-months old, ADG6=Average daily gain from 3 to 6-months old, ADG8=Average daily gain from 6 to 8-months old, ADG12=Average daily gain from 8 to 12-months old. Means in the same column with different superscript differ significantly (\* = p<0.05) or (\*\* = p<0.01).

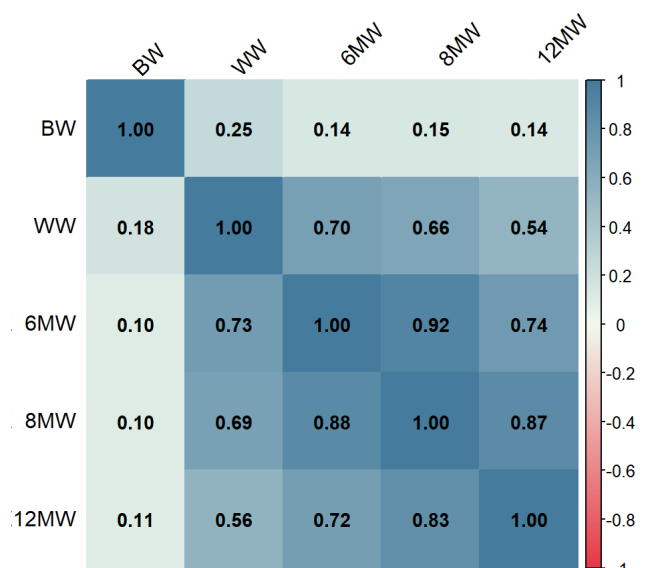


Figure 2. Phenotypic correlation (above diagonal) and genetic correlation (below diagonal) of Etawah Grade (EG) goat. BW=Birth weight, WW=Weaning weight, 6MW=6-months weight, 8MW=8-months weight, 12MW=12-months weight.

Table 4. Estimates of the (co)variance components and the genetic parameters studied for the traits of Etawah Grade (EG) goats

Traits	$\sigma_a^2$	$\sigma_e^2$	$\sigma_p^2$	h <sup>2</sup> ±SE
BW	0.100	0.217	0.317	0.314±0.028
WW	3.219	8.889	12.108	0.265±0.034
6MW	7.439	13.640	21.079	0.352±0.038
8MW	6.893	18.268	25.161	0.273±0.054
12MW	7.661	22.359	30.020	0.254±0.052
ADG3	0.0004	0.001	0.0014	0.254±0.034
ADG6	0.0002	0.002	0.0022	0.135±0.029
ADG8	0.0004	0.002	0.0024	0.161±0.053
ADG12	0.0001	0.001	0.0011	0.085±0.034

Note: BW=Birth weight, WW=Weaning weight, 6MW= 6-months weight, 8MW=8-months weight, 12MW=12-months weight, ADG3=Average daily gain from 0 to 3-months old, ADG6=Average daily gain from 3 to 6-months old, ADG8=Average daily gain from 6 to 8-months old, ADG12=Average daily gain from 8 to 12-months old,  $\sigma_a^2$  = the additive genetic variance of the animal,  $\sigma_e^2$  = the residual variance,  $\sigma_p^2$  = the phenotypic variance, and SE= Standard error.

Table 5. Estimated body weight genetic trend of Etawah Grade goat (kg year<sup>-1</sup>)

BW	WW	6MW	8MW	12MW
0.006 ± 0.001**	0.048 ± 0.006**	0.044 ± 0.012**	-0.006 ± 0.019	0.144 ± 0.016**

Note: BW=Birth weight, WW=Weaning weight, 6MW= 6-months weight, 8MW=8-months weight, 12MW=12-months. \*\* = p<0.01 level of significance

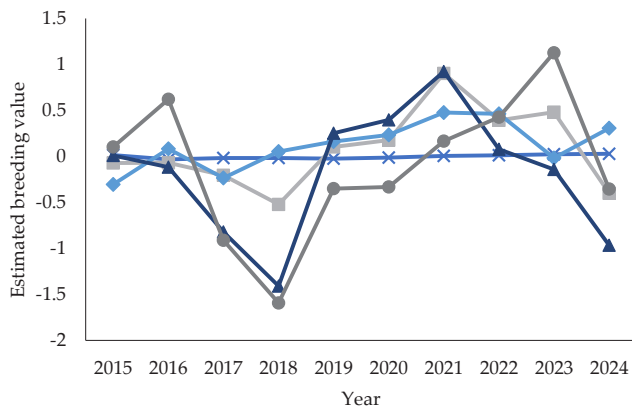


Figure 3. Genetic trend of Etawah Grade (EG) goat body weight over years. —●— BW; —■— WW; —▲— 6MW; —◆— 8MW; —●— 12MW.

for BW showed minimal fluctuation, indicating that it remained relatively stable from year to year. In contrast, the genetic trend for WW, 8MW, and 12MW showed a slight decline from 2016 to 2018, then continued to decline, reaching a peak in 2021. A different pattern was observed at 6MW, where the genetic trends showed a relatively stable increase from 2016 to 2024.

A similar pattern was observed for average daily gain. The genetic trends for ADG3, ADG6, and ADG12 increased by 0.0004, 0.0002, and 0.0003 kg year<sup>-1</sup>, respectively, while ADG8 decreased by 0.0003 kg year<sup>-1</sup> (Table 6 and Figure 4). Highly Significant genetic trends (p<0.01) were observed for every average daily gain, except for ADG8, which showed a significant genetic

trend (P<0.05). The genetic trends for average daily gain fluctuated, with ADG3 and ADG8 showing a declining tendency observed from 2021 onward. ADG12 showed a sharp decline between 2023 and 2024. In contrast, the genetic trend for ADG6 remained relatively stable and showed an increasing tendency compared to the other traits.

### DISCUSSION

The overall means of BW, WW, 6MW, 8MW, and 12MW observed in this study were 3.491±0.008 kg, 14.754±0.060 kg, 21.223±0.085 kg, 26.062±0.151 kg, and 31.062±0.167 kg, respectively. The BW recorded aligns with previous findings on Turkish Saanen goats (Erdoğan Ataç *et al.*, 2023) and exceeds those reported for Inner Mongolia White Cashmere goats (Shi *et al.*, 2024) and Boer x Highland goats (Tesema *et al.*, 2021), with values of 3.33, 2.54, and 2.52 kg, respectively. The weaning weight (WW) in the present study was lower than that reported for Turkish Saanen goats (Erdoğan Ataç *et al.*, 2023), with values of 18.38 kg and 15.17 kg for Inner Mongolia White Cashmere goats (Shi *et al.*, 2024), but has a higher value than that of the Assam Hill goat (Sarma *et al.*, 2019). Rout *et al.* (2018) reported lower 6MW, 8MW, and 12MW values for Jamunapari goats compared to those observed in the present study, with respective values of 14.5, 19.4, and 23.9 kg. Similarly, Magotra *et al.* (2021) reported lower 6MW, 8MW, and 12MW body weights in Beetal goats compared to the present study, with values of 13.8, 17.8, and 20.2 kg, respectively. Variations in body weight among goat

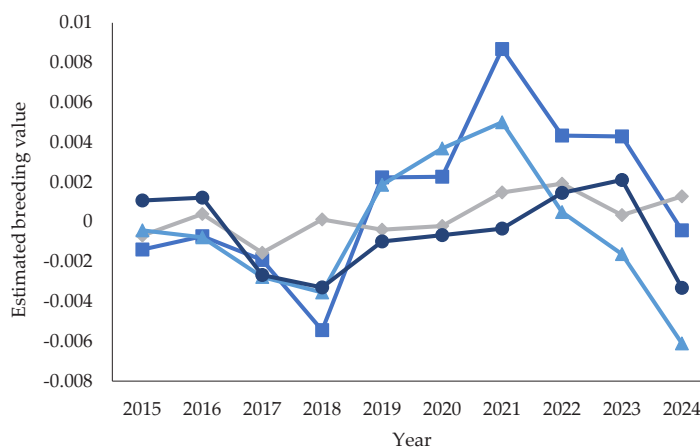


Figure 4. Genetic trend of Etawah Grade (EG) goat average daily gain on years. —■— ADG3; —▲— ADG6; —◆— ADG8; —●— ADG12.

Table 6. Estimated average daily gain genetic trend of Etawah Grade goat (kg day<sup>-1</sup> year<sup>-1</sup>)

ADG3	ADG6	ADG8	ADG12
0.0004±0.00007**	0.0002 ± 0.00005**	-0.0003 ± 0.0001*	0.0003± 0.00005**

Note: ADG3=Average daily gain from 0 to 3-months old, ADG6=Average daily gain from 3 to 6-months old, ADG8=Average daily gain from 6 to 8-months old, ADG12=Average daily gain from 8 to 12-months old. \* = p<0.05 and \*\* = p<0.01 level of significance.

breeds are primarily determined by genetic potential and breed-specific production objectives. Cashmere-type goat is more adapted for fiber production rather than rapid growth or large body size (Gawat *et al.*, 2023). Small-framed goat breeds are typically found in harsh environments, where their smaller body weight represents a trade-off that enhances reproductive efficiency and environmental adaptability (Amiri *et al.*, 2023). However, dairy-type goats generally have large body sizes, and the males are often utilized for meat production, resulting in relatively high body weight (Gawat *et al.*, 2023).

The overall mean and standard error values for ADG3, ADG6, ADG8, and ADG12 of the EG goat were  $0.124 \pm 0.001$  kg day<sup>-1</sup>,  $0.090 \pm 0.001$  kg day<sup>-1</sup>,  $0.091 \pm 0.002$  kg day<sup>-1</sup>, and  $0.068 \pm 0.001$  kg day<sup>-1</sup>, respectively. Tesema *et al.* (2021) reported lower average daily gain values in crossbred Boer goats, with  $0.080$  kg day<sup>-1</sup> for ADG3,  $0.038$  kg day<sup>-1</sup> for ADG6,  $0.042$  kg day<sup>-1</sup> for ADG8, and  $0.030$  for ADG12. In contrast, Wang *et al.* (2024b) reported higher average daily gain values in Dumeng sheep compared to the present study, with ADG3 and ADG6 values of  $0.302$  kg day<sup>-1</sup> and  $0.232$  kg day<sup>-1</sup>, respectively. The observed differences in growth traits between the present and previous studies may be attributed to variations in agroclimatic conditions and the genetic backgrounds of the breeds.

Significant differences ( $p < 0.01$ ) in body weight and average daily gain were observed between male and female goats across all age groups. Male EG goats showed higher body weights and average daily gains than females at every age. These findings are consistent with previous research, which indicated that male goats demonstrated a higher growth rate than female goats (Markos *et al.*, 2023). Phenotypic differences between males and females are referred to as sexual size dimorphism and are primarily attributed to difference in endocrine conditions and associated with nutrient requirements (Ghafouri-Kesbi & Baneh, 2018). Sex hormones influence the growth-related genes, even though males and females share the same genome. Androgen and estrogen hormones are known to have different concentrations between males and females and influence growth traits (Ghione & Dean, 2025). High levels of androgen hormones in male goats enhance muscle development by increasing the protein synthesis rates (Tesema *et al.*, 2022). In contrast, estrogen in females delays growth by restricting long bones' elongation, resulting in lower body weight compared to males, but supporting earlier sexual maturity (Ghione & Dean, 2025). High estrogen levels in female goats can also reduce dry matter intake, further affecting their growth (Safdar & Sadeghi, 2015). Sexual size dimorphism has important implications for management and breeding strategies, as rapid muscle development in males makes male goats more suitable for meat production.

Type of birth had a highly significant effect ( $p < 0.01$ ) on all traits, except ADG12, for which no significant effect ( $p > 0.05$ ) was observed. Single-born goats had the highest BW, WW, 6MW, 8MW, ADG3, and ADG6 compared to other birth types. The 12MW showed relatively similar values among all types of birth. Previous studies have also reported lower body weight and slower growth

in multiple-born kids in both EG goats (Husen *et al.*, 2025) and Boer goats (Zhang *et al.*, 2009). The variation in growth rate among birth types is influenced by intrauterine competition for space and nutrients (Gootwine, 2020). A single-born goat kid would not have to compete to get space and nutrients in the uterus during the embryonic period. Differences in growth and body weight during the weaning period are further influenced by competition for milk from the doe during the suckling period. Limited milk production of doe goats during lactation may result in lower growth rates for multiple-born kids compared to single-born kids (Shi *et al.*, 2024). Lower body weight during the post-weaning period in multiple-born kids may be influenced by a slower growth rate during the suckling period compared with single-born kids (Hasan *et al.*, 2014). After the suckling period, the maternal effect becomes minimal, and the feeding program shifts to free feeding. As animals grow older, their physical fitness continues to improve, and their immunity gradually strengthens (Shi *et al.*, 2024). This effect allowed goats with multiple-birth types to achieve similar or even faster growth rates compared to single-born kids.

Year of birth had a highly significant ( $p < 0.01$ ) effect for all traits, although the trend fluctuated across years (Table 2). BW remained relatively stable from 2015 to 2024, ranging from 3.37 to 3.59 kg, with the lowest BW being reached in 2019 and the highest in 2020. The lowest WW, 6MW, 8MW, and 12MW, were observed for goats born in 2018, while the highest WW was observed in 2021 with the value of 17.37 kg. The highest trend of 6MW, 8MW, and 12MW was observed in 2023 with values of 24.34, 28.77, and 39.04 kg, respectively. The lowest of ADG3, ADG6, ADG8 was in 2018 with the value of  $0.090 \pm 0.002$  kg day<sup>-1</sup>,  $0.055 \pm 0.003$  kg day<sup>-1</sup>, and  $0.038 \pm 0.008$  kg day<sup>-1</sup>, respectively. The highest value of ADG3 ( $0.152 \pm 0.002$  kg day<sup>-1</sup>) and ADG8 ( $0.111 \pm 0.004$  kg day<sup>-1</sup>) were reached in 2021, while the highest ADG6 was observed in 2023 with the value of  $0.110 \pm 0.002$  kg day<sup>-1</sup>. The highest ADG12 was reached in 2023 ( $0.095 \pm 0.002$  kg day<sup>-1</sup>) and the lowest in 2024 ( $0.042 \pm 0.013$  day<sup>-1</sup>). The variation in body weight and growth rate across years is attributed to climate change, which affected feed availability during those years (Menezes *et al.*, 2016). The differences in goat growth traits across years were also influenced by the management practices implemented in each respective year, including health management and feeding management (Hasan *et al.*, 2014).

BW, WW, 6MW, 12MW, ADG3, ADG6, and ADG12 were significantly affected by season of birth ( $p < 0.01$ ), while 8MW and ADG8 were not significantly affected ( $p > 0.05$ ). Goats born in the rainy season showed higher body weight and average daily gain in early growth traits (BW, WW, and 6MW) compared to those born in the dry season. On the contrary, goats born in the dry season showed better performance in later growth traits (8MW and 12MW). Abebe *et al.* (2023) reported a similar result that BW, WW, and 6MW of lambs born in the rainy seasons were heavier than those born in the dry season. Early growth traits, particularly BW and WW, are largely determined by the dam's nutritional intake. During the rainy season, vegetation is more varied and nutritious than in the dry season. Lo *et al.* (2024) noted that the

crude protein content of the forage during the rainy season is higher than during the dry season, whereas the dry matter content during the dry season was higher than during the rainy season. Better feed availability and nutritional quality during the rainy season are associated with endocrine conditions in dams, particularly increased prolactin secretion and milk production, thereby contributing to higher weaning weights (Farrag, 2022). Elevated insulin levels during the rainy season stimulate anabolic processes in muscle and liver tissues, improving carbohydrate and lipid metabolism (Murillo-Ortiz *et al.*, 2013; Song *et al.*, 2025). These metabolic effects contribute to improved post-weaning growth and are positively associated with increased neonatal birth weight through enhanced maternal nutrient utilization (Song *et al.*, 2025). In later growth phases, growth is more influenced by dry matter intake, organic matter intake, and energy supply (Wang *et al.*, 2024a). This phenomenon explains the higher BW, WW, and 6MW in goats born during the rainy season, while 12MW is higher in those born during the dry season. Higher body weight at 12MW during the dry season may result from compensatory growth after nutritional restriction, increased feed intake under low-quality forage conditions, and improved nutrient utilization efficiency during post-weaning growth.

Parity had a highly significant ( $p < 0.01$ ) effect on BW, WW, 6MW, 8MW, 12MW, and ADG3, a significant effect ( $p < 0.05$ ) on ADG6, and no effect ( $p > 0.05$ ) on ADG8 and ADG12. The highest BW was observed in offspring from second or third parity dams, while the lowest values were recorded in offspring from first parity dams. WW, 6MW, 8MW, and 12MW were the highest in offspring from first-parity dams, with body weight decreasing gradually with the increase in parity. ADG3 and ADG6 showed a gradual decrease as the number of parities increased. Parity of dams influences kid performance due to the development of the dam's uterus with increasing age and frequency of parturition (Hasan *et al.*, 2014). Similar effects of parity on body weight have been reported in previous studies (Ehsaninia, 2021). Multiparous dams tend to produce larger litter size compared to primiparous dams (Mamutse *et al.*, 2023). There is an antagonistic relationship between body weight and litter size, particularly during early growth stages (Besufkad *et al.*, 2024), which may explain the higher BW, WW, 6MW, and 8MW in offspring from primiparous dams compared to those from multiparous dams. Early growth of the goat is strongly affected by maternal influences, since the nutrient availability depends primarily on the dam's nutritional status during the prenatal period. However, maternal effects gradually decline as offspring age.

The heritability of BW, WW, 6MW, 8MW, and 12MW were estimated at  $0.314 \pm 0.028$ ,  $0.265 \pm 0.034$ ,  $0.352 \pm 0.038$ ,  $0.273 \pm 0.054$ , and  $0.254 \pm 0.052$ , respectively. Heritability values above 0.4 are classified as high heritability, 0.2 to 0.4 as medium heritability, and below 0.2 as low heritability (Jonker *et al.*, 2018). Overall, the estimated heritability in this study was classified as moderate. Previous studies reported a higher heritability in West African Dwarf goat of BW (0.45), WW (0.57), 8MW (0.74), 12MW (0.49) than this study, except for 6MW (0.04) (Ofori & Hagan, 2020). In contrast, lower heritability estimates were found in Beetal goats for BW (0.07), 8MW (0.17), and

12MW (0.10), with a similar heritability value for WW (0.27) and a higher value for 6MW (0.37) (Magotra *et al.*, 2021). The estimated heritability of average daily gain traits was low to moderate, ranging from 0.085 to 0.254, and decreased gradually with increasing animal age. Magotra *et al.* (2021) reported a similar pattern and lower heritability values for average daily gain in Beetal goats, with 0.21 for ADG3, 0.21 for ADG6, and 0.07 for ADG6. Higher heritability for ADG3 (0.31) was reported in Boer goats (Menezes *et al.*, 2016) and Cashmere goats (Wang *et al.*, 2022). Rout *et al.* (2018) found higher heritability for ADG6 and ADG12, at 0.37 and 0.17, respectively.

The differences in heritability estimates were due to goat breed and the evaluation methods used (Ladeira *et al.*, 2021). Differences in estimating heritability may also be influenced by sample size and the fixed effects included in the model. Previous studies on the same breed reported higher heritability estimates than those found in the present study. Hasan *et al.* (2014) used a smaller sample size and did not account for non-genetic factors as fixed effects. A larger sample size can comprehensively capture variation, making the estimated value more accurate, higher precision, and stronger statistical power, thereby facilitating the discovery of genetic laws (Shi *et al.*, 2025). Non-genetic factors such as gender, breed, dam age, season, year, and type of birth significantly influence determining trait variations and should always be taken into account as fixed effects (Wang *et al.*, 2024b).

Body weight traits showed higher heritability than average daily gain, indicating that environmental variation has a greater impact on average daily gain than on body weight. Higher heritability estimates indicate that body weight traits are more reliable selection criteria than average daily gain in EG goats. Among the traits, 6MW had the highest heritability and can be considered a suitable selection criterion at the early growth stage of EG goats, as it demonstrates the greatest potential to be passed on to the next generation. High heritability estimation indicates that the variation in that trait is mainly influenced by genetic factors rather than environmental factors (Fathoni *et al.*, 2022). Selecting for 6MW can yield higher genetic gain and faster phenotypic improvement compared to other traits. The low estimates of heritability for some traits may suggest that genetic variation is probably unobservable due to environmental factors (Rout *et al.*, 2018). Manirakiza *et al.* (2020) reported that improvement in traits with low heritability can be achieved through improved recording systems and better management practices, including feeding and health management. Maternal effect also significantly influences the expression of early growth traits; however, their influence decreases as the animal ages (Husen *et al.*, 2025; Manirakiza *et al.*, 2020). Furthermore, accounting for both maternal genetic and environmental effects is important to improve the accuracy of genetic parameter estimation in future studies.

The phenotypic and genetic correlations among BW, WW, 6MW, 8MW, and 12MW in this study ranged from weak to strongly positive. Besufkad *et al.* (2024) reported similar findings to this study, with BW showing positive but low phenotypic (0.21-0.28) and genetic correlations (0.20-0.24) with WW, 6MW, and 12MW.

A Higher phenotypic and genetic correlation between WW – 6MW, WW – 8MW, and WW–12MW was reported on West African Dwarf goats with values between 0.81-0.92 for phenotypic correlation and 0.75-0.92 for genetic correlation (Ofori & Hagan, 2020). Tesema *et al.* (2021) also reported high positive correlations between 6MW and 8MW (0.79) and between 6MW and 12MW (0.71). Positive genetic correlations among the observed traits indicate that these traits are influenced by genes that control more than one trait (pleiotropy) (Habtegiorgis *et al.*, 2022). The positive genetic correlations across all traits in this study indicate that selection for any trait should result in positive genetic change in the others. Indirect selection can also be applied to traits with strong genetic correlations, particularly for traits that are difficult to measure (Bourdon, 2014). Among the evaluated traits, 6MW is the most promising selection criterion for growth in EG goats, as its high heritability and strong genetic correlations are expected to achieve greater genetic improvement in other traits.

The estimated genetic trends in this study indicated improvements in all evaluated traits, except for 8MW and ADG8. Rout *et al.* (2018) reported higher estimated genetic trends for BW, WW, 6MW, 8MW, and 12MW in Jamunapari goats, with values of 0.037, 0.080, 0.118, 0.144, and 0.199 kg year<sup>-1</sup>, respectively. In contrast, Tesema *et al.* (2021) observed declines in genetic trends for BW, WW, and 6MW in Boer x Highland goats, with values of 0.0207, 0.0805, and 0.0317 kg year<sup>-1</sup>, while 8MW and 12MW increased by 0.1692 and 0.2133 kg year<sup>-1</sup>, respectively. Ren *et al.* (2024) reported higher genetic trends for ADG3 but lower genetic trends for ADG6 in Luzhong sheep, at 0.0012 kg day<sup>-1</sup> and 0.00002 kg day<sup>-1</sup>, respectively. Low estimated genetic trends may be attributed to climatic conditions that reduced feed availability and decreased livestock productivity in the observed year (Habtegiorgis *et al.*, 2022). The positive and significant genetic trends observed for BW, WW, 6MW, 12MW, ADG3, ADG6, and ADG12 indicate that the selection program implemented at the breeding station has been effective in improving these traits genetically over the years. However, these trends observed were lower than those reported in previous studies across several goat breeds. The low estimated genetic trend suggests that the selection program implemented at the breeding station in recent years has not been fully effective in achieving optimal genetic improvement. The low estimated genetic trend indicates that the selection differential was not maximized; other factors contributing to the low genetic trend include selection practices that do not account for estimated breeding values and the culling of animals with low productivity at specific ages (Tesema *et al.*, 2021; Gholizadeh & Ghafouri-Kesbi, 2015). Several strategies that can be implemented to enhance genetic trends include reducing the generation interval and increasing selection intensity (He *et al.*, 2023; Kasinathan *et al.*, 2015). The most practical approach to reducing the generation interval is to shorten the length of sire usage and to implement reproductive technologies such as artificial insemination (AI). The application of genomic selection has also been proven to reduce the generation interval, as replacement animals can be selected at a relatively young age (de Roos *et al.*, 2011).

These findings emphasize the need to account for non-genetic variation when estimating genetic parameters for selection programs in EG goat populations. Adjusting body weight for non-genetic factors will reduce bias in estimating genetic parameters. In future studies, both maternal genetic and maternal environmental effects should be considered in the estimation of genetic parameters to increase the accuracy of the estimates, especially for early growth traits. The findings of this study may provide a basis for decision-making in production management to prevent performance decline driven by the effects of non-genetic factors. Several strategies, including management improvement and implementation of technology, are required to enhance the genetic trend for growth traits in EG goats.

## CONCLUSION

Growth traits in EG goats are significantly influenced by several non-genetic factors, including sex, birth type, year of birth, season, and parity. Notably, only 8MW was unaffected by the season of birth. The estimated heritability of growth traits in EG goats was moderate, suggesting sufficient genetic variability to respond to selection. Among the evaluated traits, 6MW exhibited the highest heritability and strong genetic associations with later growth traits; it could serve as an effective selection criterion in EG goat breeding programs. A positive genetic correlation among growth traits suggests that improvement in one trait may lead to favorable responses in related traits. The negative genetic trend may indicate inconsistencies in selection practices or management conditions during the study period.

## CONFLICT OF INTEREST

C. Sumantri and A. Gunawan serve as editors of the *Tropical Animal Science Journal* but have no role in the decision to publish this article. The authors state they have no competing interests.

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## DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used ChatGPT and Grammarly in order to improve the readability and language of the work. After using this tool/service, the author(s) reviewed and edited the content as needed and take full responsibility for the content of the publication.

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