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Research article

Estimation of genetic parameters for growth traits and kleiber ratio in dorper sheep breed

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ABSTRACT

The study aimed to estimate genetic and phenotypic parameters for growth traits and Kleiber ratio in Dorper sheep breed. Data used in this study were collected over 12 years (2012–2023) at Debre Birhan Agricultural Research Center sheep research station in Ethiopia. Studied traits were body weights at birth (WT0), weaning (WT3), six month (WT6), and yearling (WT12) age; average daily gains from birth to weaning (ADG0-3), from weaning to six months (ADG3-6), from six months to yearling (ADG6-12); and Kleiber ratios from birth to weaning (KR1) and from weaning to six months (KR2). The (co)variance components were estimated with different animal models using Average Information Restricted Maximum Likelihood (AI-REML) procedure. The best-fitted model for each trait was determined using likelihood ratio tests. Phenotypic performance for WT3, WT6, WT12, ADG0-3 and ADG3-6 showed a decline trend at a rate of 0.216 kg, 0.794 kg, 0.671 kg, 2.601 g and 4.865 g over years respectively. However, WT3, WT6, WT12, ADG0-3 showed a positive genetic improvement trend at a rate of 0.029 kg, 0.043 kg, 0.049 kg and 0.257 g over years respectively. Year of birth had a significant effect ($P < 0.001$) on all studied traits. Model including direct genetic as well as permanent environmental effect (Model 2) was chosen as the most appropriate model for WT0. Model which included only direct genetic effect (Model 1) was the best-fit model for all other studied traits. Direct heritability estimates based on suitable models were 0.07 ± 0.06, 0.11 ± 0.06, 0.09 ± 0.07, 0.11 ± 0.09 0.11 ± 0.06, 0.00 ± 0.04, 0.15 ± 0.07 and 0.00 ± 0.04 for WT0, WT3, WT6, WT12, ADG0-3, ADG3-6, KR1 and KR2 respectively. The variance ratio for the permanent environmental effect was 0.13 ± 0.04 for WT0. Genetic correlations among the traits ranged from negative (−0.39) for WT0-KR1 to high (0.99) for WT3-ADG0-3 and phenotypic correlations ranged from negative (−0.31) for WT0-KR1 to high (0.98) for WT3-ADG0-3. The low direct heritability estimates for the studied traits indicated that genetic improvement by direct selection might be difficult. Further investigation for the unexpected declined trend of phenotypic performance over years need to be required.

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1. Introduction

The Dorper is a hardy South African composite mutton breed, developed in the early 1940s from a cross between Dorset Horn ram with Blackhead Persian ewes with the aim to develop a high quality carcass-producing breed in the arid area of South Africa. Currently, the breed is the second most common sheep breed in South Africa and has spread to many other countries throughout the world [1–3]. Dorper sheep was first introduced to Ethiopia from the republic of South Africa in 1981 as improver breed for the Black Head Somali sheep in the Somalia region of Ethiopia. The breed was later imported by the Ethiopian Sheep and Goat Productivity Improvement Program (ESGPIP) in 2007 and the Amhara Regional Agricultural Research Institute (ARARI) in 2011. The goal was to establish a purebred nucleus flock at Debre Birhan Agricultural Research Center (DBARC) and to use the breed as improver breed in a crossbreeding program. This program was designed to take advantage of the breed's fast growth rate and large carcass, while also leveraging the adaptability of indigenous breeds [4]. The ultimate aim of this effect was to facilitate the development of the Dorper valley in the lowland areas of Amhara region. Several studies on the Dorper based crossbreeding program have documented the superiority of Dorper crossbred lambs as compared to their local sheep breeds [5–8]. Many Authors including [9,10], demonstrated that carcass related traits in sheep have moderate to high heritability. Due to rapid weight gain, large body size, high carcasses quality, higher market prices, and non-selective grazing ability of the crossbred lambs, it has become one of the preferred breeds for the genetic improvement of local breeds through crossbreeding programs in the central highland of Ethiopia [11,12].

The Dorper sheep breeding programs was focused on the development of the purebred Dorper sheep through selective breeding, synthetic breed development from Dorper-local sheep crossing, and utilization of the breed as an improver breed in a crossbreeding program. Quantitative traits such as growth traits and Kleiber ratio are a complex traits which are known to be influenced by non-genetic and genetic factors, as well as their interaction. The ability of the dam to provide optimum nursing conditions has a direct and maternal genetic effect on the phenotypic expression of these traits in the offspring [8,13,14]. Thus, identifying genetic and non-genetic sources of variation in economically important traits is a key component in designing efficient breeding programs. Considering the direct and maternal genetic effect in genetic parameter estimates is crucial especially when the direct-maternal genetic correlation is negative [15,16]. The animal models which do not account for maternal effects may overestimate direct heritability, leading to biased prediction of response to selection [17]. An effective genetic improvement programs requires an in-depth study of the influence of environmental factors, knowledge of genetic parameters and genetic relationship between the trait of interest [8,15]. Genetic parameter estimates for different growth traits of Pure Dorper sheep were estimates by several authors [3,18–20]. However, genetic parameter estimates for growth traits and Kleiber ratios which are required for designing selective breeding programs have not been reported for pure Dorper sheep in Ethiopia. Therefore, the present study was conducted to estimate genetic parameters for different growth traits and Kleiber ratios in Dorper sheep breed at DBARC.

2. Materials and methods

2.1. Dorper sheep breeding flock

The present study utilized data from a breeding flock of Dorper sheep maintained at Debre Birhan Agricultural Research Center from 2012 to 2023. The center is situated in the central highlands of Ethiopia, approximately 120 km northeast of Addis Ababa. The location has an altitude of 2765 m above sea level, with coordinates of 09°36′23″N latitude and 39°39′10″E longitude. The area experiences a bimodal rainfall pattern, with the primary rainy season occurring from June to September and a shorter rainy season expected between February/March and April/May. According to meteorological data obtained from DBARC, the average annual rainfall during the study period was recorded as 865 mm. The center has an average minimum temperature of 6.59 °C and an average maximum temperature of 19.87 °C. Frost is commonly observed from October to December/January. The foundation flock of Dorper sheep at DBARC was established in 2011 by acquiring 100 females and 16 males from the Republic of South Africa. Maiden ewes were exposed to rams based on their body weight, with the minimum age for first exposure being 12 months. The mating system generally followed a single-sire approach, where one carefully selected breeding ram was assigned to a group of 20–25 ewes. The mating period lasted for an average of 60 days. Selection focused on the breeding rams, with replacement rams chosen based on estimated breeding values (EBVs) for six-month weight using WOMBAT software. Rams with high EBVs and desirable physical conformation were selected to enhance growth and carcass yield. Ewes that failed to produce offspring for two to three years were culled from the flock. Additionally, Menz ewes, an indigenous breed from the central highland of the North Shewa zone, were mated with pure Dorper rams to produce crossbred lambs at the research center. Over the period from 2012 to 2023, approximately 1050 pure Dorper lambs, originating from 38 sires and 290 dams, were produced. Starting from 2020, the MateSel software [21] was employed to design mating groups that maximize genetic gain and control inbreeding across generations. Newborn lambs were identified using plastic ear tags, and their date of birth, sex, birth litter size, weight, and color were recorded. All animals were regularly weighed at birth, 3, 6, and 12 months of age. Lambs were raised alongside their dams until weaning, which typically occurred between 85 and 95 days. After weaning, lambs born in the same lambing season were managed as a collective flock. Birth weight was recorded either at the time of birth or within 24 h thereafter. Weaning, six-month, and yearling weights of the lambs were taken at five-day intervals from the actual weighing dates and adjusted to reflect the precise ages of 90, 180, and 365 days, respectively.

All animals were allowed to graze on natural pasture during the day from 8:30–12:00 A.M. and 2:00–5:00 P.M. and penned at night during dry and short rainy seasons. On the other hand, because of high occurrence of mortality due to fasciolosis outbreak in 2014, all animals were forced to kept indoors day and night during the main rainy season (from July to September) and fed dry hay as a basal diet without any supplementation of vitamins and minerals premix. However, the animals were fed green forage and grass during this season with a cut and carry feeding system only since 2019. The animals were supplemented with 200–400 g/head/day mixed concentrate depending up on status, age category, and availability of grazing feed. The supplementary commercial concentrate consisting of noug (*Guizotia abyssinica*) cake, wheat bran, limestone and salt. All experimental animals in the research center were regularly (three times per year) treated against internal parasites and were vaccinated against the common viral diseases of the area.

2.2. Data analyses

The data set analyzed consisted of 1050 lamb records born between 2012 and 2023 from 38 sires and 290 dams (Table 1). Traits considered for analysis were birth weight (WT0), weaning weight (WT3), six months weight (WT6), yearling weight (WT12), average daily gain from birth to weaning (ADG0-3), average daily gain from weaning to six months (ADG3-6), average daily gain from six months to yearling (ADG6-12), Kleiber ratio from birth to weaning (KR1) and Kleiber ratio from weaning to six months (KR2). The Kleiber ratio is believed to be an efficient criterion for feed efficiency under low-input range conditions which provides a good indication of how economically an animal grows [22]. Kleiber ratio was computed as follows $KR1 = ADG0\text{-}3/WT3^{0.75}$ and $KR2 = ADG3\text{-}6/WT6^{0.75}$, accordingly to Ref. [23].

Fixed effects for body weight, average daily gain and Kleiber ratio were estimated using the GLM procedure of SAS 9.1 software [24]. The fixed effects include year of birth in 12 classes (2012–2023), sex of lambs in two classes (male and female), birth litter size in two classes (single and twin), parity of dam in five classes and season of lambing in three classes (rainy, dry and short rainy season). Means were compared using Tukey-kramers test.

The model used for the analysis of growth, daily weight gain and Kleiber ratio was

$$Y_{ijklmn} = \mu + Y_i + Bt_j + Bs_k + P_l + S_m + e_{ijklmn}$$

Where Y_{ijklmn} is an observation for body weight, average daily gain and kleiber ratio at different age; μ is overall mean; Y_i is fixed effect of year of birth; Bt_j is fixed effect of birth type; Bs_k is fixed effect of birth season; P_l is fixed effect of parity; S_m is fixed effect of sex of lamb and e_{ijklmn} is residual error.

The (co)variance components and corresponding genetic parameters were estimated using Average Information Restricted Maximum Likelihood (AI-REML) procedure using WOMBAT software [25]. Multivariate techniques need a large sample of data to give meaningful results; otherwise, the results are meaningless due to high standard errors [8]. Thus in this study, a univariate animal model was fitted due to data structure. For genetic and phenotypic correlations, a multivariate analysis was used. The convergence criteria was noted as follows: (1), a change in log L of $<5 \times 10^{-4}$, (2) a change in parameters of $<10^{-8}$ and (3) a gradient vector norms $<10^{-3}$.

The following six univariate animal models were tested for each trait. Fixed effects with significant effect in the linear model analysis were included in the genetic model.

The statistical model used were on:

Model (1) $y = \mathbf{X}\beta + \mathbf{Z}_a\alpha + e$

Model (2) $y = \mathbf{X}\beta + \mathbf{Z}_a\alpha + \mathbf{Z}_{pe}pe + e$

Model (3) $y = \mathbf{X}\beta + \mathbf{Z}_a\alpha + \mathbf{Z}_m m + e \; Cov(\alpha, m) = 0$

Model (4) $y = X\beta + Za\alpha + Zmm + e \; Cov(\alpha, m) \neq 0$

Model (5) $y = \mathbf{X}\beta + \mathbf{Z}_a\alpha + \mathbf{Z}_m m + \mathbf{Z}_{pe}pe + e \; Cov(\alpha, m) = 0$.

Model (6) $y = \mathbf{X}\beta + \mathbf{Z}_a\alpha + \mathbf{Z}_m m + \mathbf{Z}_{pe}pe + e \; Cov(\alpha, m) \neq 0$, where y is a vector of observations for the studied traits; β, α, m, pe and e are vectors of fixed effects, direct additive genetic effects, maternal genetic effects, permanent environment effects and the residual effects, respectively. $\mathbf{X}$, $\mathbf{Z}_a$, $\mathbf{Z}_m$ and $\mathbf{Z}_{pe}$ are corresponding design matrices associating the fixed effect, direct additive genetic effects,

Table 1
Characteristics of data structure.

Traits	No of records	No of animals	Sire[a]	Dam[a]	Mean[b]	CV (%)
WT0 (kg)	1050	1151	38	290	3.63 ± 0.89	20.71
WT3 (kg)	760	863	35	254	15.84 ± 5.30	22.82
WT6 (kg)	556	660	31	216	21.03 ± 5.82	23.87
WT12 (kg)	462	556	32	191	31.25 ± 6.98	18.44
ADG0-3 (g/day)	760	863	35	254	134.11 ± 42.05	28.20
ADG3-6 (g/day)	554	658	31	216	52.51 ± 41.01	68.41
ADG6-12 (g/day)	427	522	31	185	52.22 ± 29.08	44.62
KR1	760	863	35	254	16.60 ± 2.40	12.96
KR2	554	658	31	216	4.94 ± 3.56	64.72

[a] Sires and dams with progeny records.

[b] Means ± standard deviations from 2012 to 2023; WT0-WT12: weight at birth, three months, six months and yearling age, respectively; ADG0-3: average daily gain from birth to weaning; ADG3-6: average daily gain from weaning to six months; ADG6-12: average daily gain from six months to yearling; KR1: Kleiber ratio birth to weaning; KR2: Kleiber ratio weaning to six months; CV.: Coefficient of variation.

maternal additive genetic effects and permanent environmental effects to vector of y. Total heritability (h_t^2) was calculated according to Ref. [26] using the following formula:

$$h_t^2 = \frac{\sigma_a^2 + 0.5\sigma_m^2 + 1.5\sigma_{am}}{\sigma_p^2}$$

Where σ_a^2, σ_m^2, σ_{am} and σ_p^2 are direct additive genetic variance, maternal genetic variance, the covariance between direct and maternal additive genetic effect and total phenotypic variance, respectively. Direct heritability (h_a^2), maternal heritability (h_m^2) and relative permanent environmental effects (c^2) were calculated as ratios of estimates of σ_a^2, σ_m^2 and σ_c^2 respectively, to the phenotypic variance σ_p^2.

Likelihood ratio tests was used to select best model and to test the significance of random effects for each traits. The significance of model comparison was done with and without including the effect as a random effect and compared the final log-likelihoods (maximum log L) by chi-square distribution with one degree of freedom [27].

$$\chi^2_{1df} = 2\left[max\ log\ L_{(f)} - max\ log\ L_{(r)}\right]$$

Where max log $L_{(f)}$ is maximum log-likelihood for full model; max log $L_{(r)}$ is maximum log-likelihood for reduced model. A random effect was considered to have significant effect, when its inclusion resulted significant ($P < 0.05$) increase in log-likelihood compared to the model in which it was ignored. However, when the difference between the values of log-likelihood is not greater than a critical value of chi-square ($p < 0.05$), the simplest model that has fewer parameters was considered to be the best model.

3. Results and discussion

3.1. Non-genetic effects

Table 2 presents effect of non-genetic factors on the phenotypic growth performance and Kleiber ratio of Dorper sheep. Due to culling, death, and distribution of breeding animals for genetic improvement programs, the number of records was decreased from

Table 2

Least-squares means (±SE) of live weight of Dorper sheep.

Parameters	WT0 (kg)	WT3 (kg)	WT6 (kg)	WT12 (kg)	ADG0-3 (g/day)	ADG3-6 (g/day)	ADG6-12 (g/day)	KR1	KR2
Birth year	***	***	***	***	***	***	***	***	***
Sex	***	ns	*	**	ns	*	*	ns	ns
Male	3.33 ± 0.07	16.10 ± 0.41	21.26 ± 0.66	31.71 ± 0.87	140.28 ± 4.25	52.46 ± 4.71	59.12 ± 3.58	17.21 ± 0.24	4.96 ± 0.42
Female	3.17 ± 0.06	15.81 ± 0.40	20.30 ± 0.64	29.92 ± 0.82	139.12 ± 4.14	45.54 ± 4.58	53.03 ± 3.41	17.31 ± 0.24	4.49 ± 0.41
BLS	***	***	***	***	***	ns	ns	ns	ns
Single	3.65 ± 0.06	17.06 ± 0.33	22.22 ± 0.53	32.30 ± 0.72	147.75 ± 3.46	50.51 ± 3.84	53.40 ± 2.93	17.40 ± 0.20	4.53 ± 0.34
Twin	2.85 ± 0.09	14.85 ± 0.53	19.33 ± 0.85	29.33 ± 1.07	131.64 ± 5.54	47.49 ± 6.12	58.74 ± 4.52	17.12 ± 0.31	4.93 ± 0.54
Parity	***	***	***	***	***	ns	*	*	ns
1	2.82 ± 0.07^{c}	14.24 ± 0.42^{b}	18.77 ± 0.67^{b}	28.46 ± 0.90^{b}	124.49 ± 4.44^{b}	47.15 ± 4.80	54.94 ± 3.71^{ab}	16.67 ± 0.25^{b}	5.00 ± 0.43
2	3.21 ± 0.08^{b}	16.05 ± 0.48^{a}	20.83 ± 0.77^{a}	31.72 ± 0.99^{a}	141.52 ± 5.00^{a}	48.32 ± 5.53	62.20 ± 4.08^{a}	17.41 ± 0.28^{a}	4.62 ± 0.49
3	3.43 ± 0.08^{a}	16.82 ± 0.48^{a}	21.70 ± 0.81^{a}	31.81 ± 1.01^{a}	147.23 ± 5.07^{a}	47.81 ± 5.81	60.40 ± 4.25^{a}	17.49 ± 0.29^{a}	4.41 ± 0.52
4	3.36 ± 0.09^{ab}	16.16 + 0.49^{a}	21.02 ± 0.79^{a}	30.51 ± 1.02^{ab}	141.50 ± 5.10^{a}	48.21 ± 5.67	47.87 ± 4.24^{b}	17.35 ± 0.29^{ab}	4.52 ± 0.50
≥5	3.43 ± 0.08^{a}	16.50 ± 0.50^{a}	21.58 ± 0.80^{a}	31.57 ± 1.07^{a}	143.75 ± 5.20^{a}	53.51 ± 5.74	54.95 ± 4.41^{ab}	17.37 ± 0.30^{ab}	5.09 ± 0.51
Birth season	***	ns	ns	ns	*	ns	ns	**	ns
Main rainy	3.36 ± 0.09^{a}	16.17 ± 0.56	20.81 ± 0.87	30.99 ± 1.11	141.36 ± 5.85	44.39 + 6.27^{b}	57.08 ± 4.69	17.30 ± 0.33^{a}	4.28 ± 0.56^{b}
Dry	3.45 ± 0.07^{a}	15.09 ± 0.45	19.69 ± 0.68	28.42 ± 0.93	127.74 ± 4.76	48.37 + 4.85^{ab}	46.64 ± 3.87	16.39 ± 0.27^{b}	4.81 ± 0.43^{ab}
Short rainy	2.94 ± 0.11^{b}	16.60 ± 0.75	21.84 ± 1.30	33.04 ± 1.68	150.00 ± 7.88	54.24 + 9.32^{a}	64.49 ± 7.27	18.10 ± 0.45^{a}	5.09 ± 0.83^{a}
Overall mean	**3.63 ± 0.03**	**15.84 ± 0.14**	**21.03 ± 0.25**	**31.25 ± 0.32**	**134.11 ± 1.52**	**52.51 ± 1.74**	**52.22 ± 1.41**	**16.60 ± 0.09**	**4.94** ± **0.15**

Means with the same superscript are not statistically different at $P = 0.05$. ns: not significant. ***$P < 0.001$; **$P < 0.01$ and * $P < 0.05$; WT0-WT12: weight at birth, three months, six months and yearling age, respectively; ADG0-3: average daily gain from birth to weaning; ADG3-6: average daily gain from weaning to six months; ADG6-12: average daily gain from six months to yearling; KR1: Kleiber ratio birth to weaning; KR2: Kleiber ratio weaning to six months.

birth (n = 1050) to yearling (n = 462). The percentage of twin birth was 12.09 % and sex ratio (male:female) was 0.88:1. Year of birth had significant effects ($P < 0.001$) in all the traits studied. Variations in animal management, grazing pasture availability, disease incidence, climatic conditions over years could be possible reasons for the significant effects of year on animal performance [28–30]. Contrary to the genetic performance (Figs. 3 and 4), phenotypic performance for WT3, WT6, WT12, ADG0-3, and ADG3-6 showed a decreasing trend a rate of 0.216 kg, 0.794 kg, 0.671 kg, 2.601 g and 4.865 g over years respectively (Figs. 1 and 2). This may be due to management difference over years. Since 2015, the animal were not allowed to graze on natural pasture during winter season, kept indoors and fed dry hay as a basal diet and supplemented with 200g head/day mixed concentrate without any supplementation of vitamins and minerals premix. This management practice could expose the animals to vitamin E deficiency, in addition as the center located in high rainfall (923 mm) areas, is expected to selenium deficiency due to leaching of selenium from the soil. Deficiency of either or both selenium and vitamin E can reduce growth, reproductive performance and immune response of the animal [31,32]. [33] reported that survival rate of Dorper sheep showed a declined trend over years at DBARC since 2015.

The results revealed that the sex of lambs had significant effects ($P < 0.05$) on WT0, WT6, WT12, ADG3-6, and ADG6-12. The same effect of sex report by Refs. [11,18] in Dorper sheep. Estrogen has a limited effect on long bone growth in females. That may be one of the reasons of females' tend to be smaller body and lighter weight compared to males [34,35]. Single born lambs had higher ($P < 0.001$) body weight than twins in WT0, WT3, WT6, WT12 and ADG0-3. This difference may be attributed to lesser availability of uterine space, insufficient availability of nutrients during pregnancy among multiple births and also the competition for dam's milk during pre-weaning period [36,37]. [38] reported significant effect of birth litter size in pre-weaning growth traits. Moreover, parity has a significant effect ($P < 0.05$) in WT0, WT3, WT6, WT12, ADG0-3, ADG6-12 and KR1. Accordingly, lambs born from dams in their 1st parity had significantly lighter weight as compared to lambs born from the successive parities. The significant effect of parity can be ascribed to difference in maternal effects and maternal behavior of ewes at different ages [36]. The same effects of parity and birth litter size were reported by Refs. [11,18,30,35,37,39], for different sheep breed. Birth season has no significant effects in most studied traits except WT0, DG0-3 and KR1. The result are contrary to the finding of [11,18], who reported that season of lambing has a significant in growth performance of Dorper sheep. This may be due to uneven distribution of lambing across season. The overall least-squares means of WT3 and ADG0-3 recorded under the present study were comparable to values reported by Ref. [11], in Dorper sheep at DBARC. Moreover, WT3, WT6 and WT12 found in the current study were comparable to Ref. [40], in Awassi × Menz sheep in Ethiopia. However, the current WT0, WT3, WT6, WT12, and ADG6-12 was lower than values reported by Ref. [18], in Dorper sheep in Kenya (3.76, 19.38, 24.33, 36.64 and 65.16 respectively). The pre-weaning KR found in this study was in close agreement with the report of [8], in Dorper × indigenous sheep breed (16.8). However, same author for Dorper × indigenous sheep reported higher value of post-weaning KR (6.4). The pre-weaning KR found in this study was higher than values reported by Ref. [41], in Nilagiri and Sandyno sheep (14.45). Moreover, higher values of kleiber ratio was reported by Refs. [35,36,39], for different sheep breed. The significant difference in growth and kleiber ratio traits among different breeds can be ascribed by difference in feed availability, management and genetic difference of the breeds.

3.2. Genetic parameters estimates

Heritability estimates fitting different models for various traits are presented in Table 3. Fitting a permanent environmental effect (Model 2) for WT0 substantially increased the log-likelihood values over that of Model 1, indicating a significant permanent environmental effect on WT0. Therefore, consideration of permanent environmental effect is crucial to obtain accurate direct heritability estimates for WT0. Based on the most appropriate Model (Model 2) for WT0, the estimates of direct and permanent environmental heritability were 0.07 ± 0.06 and 0.13 ± 0.04 respectively. Low estimates of direct heritability for WT0 in the current study was in agreement with the estimates of [42], in Muzaffarnagari sheep (0.10). However, higher direct heritability for WT0 was obtained by Ref. [43], in Iranian Baluchi sheep (0.22 ± 0.02) and by Ref. [44], in Iran-Black sheep (0.19 ± 0.04). Permanent environmental

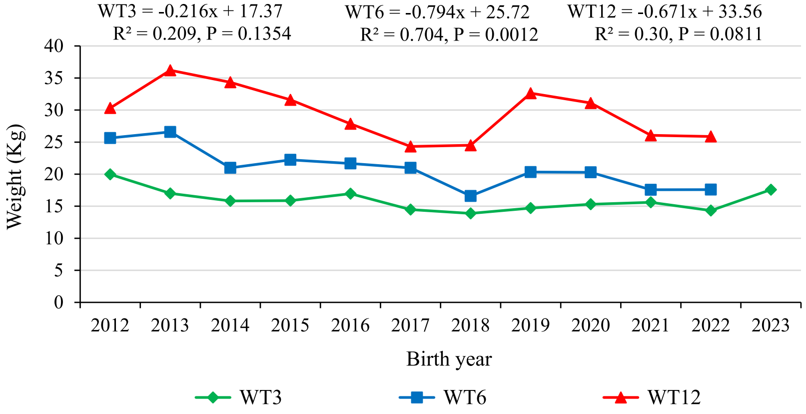

Fig. 1. Phenotypic growth trend by year of birth.

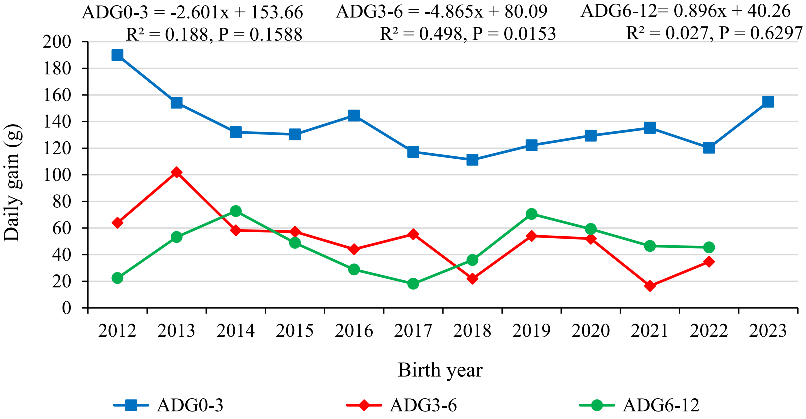

Fig. 2. Phenotypic average daily gain trend by year of birth.

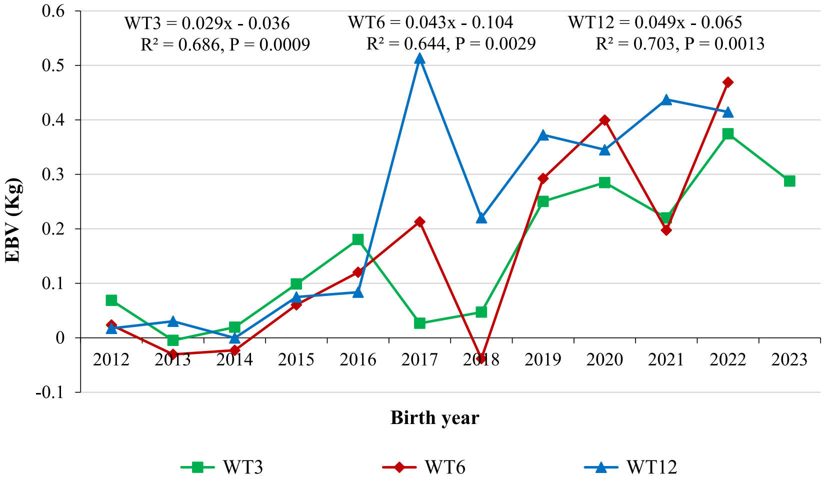

Fig. 3. Genetic body weight trend by year of birth.

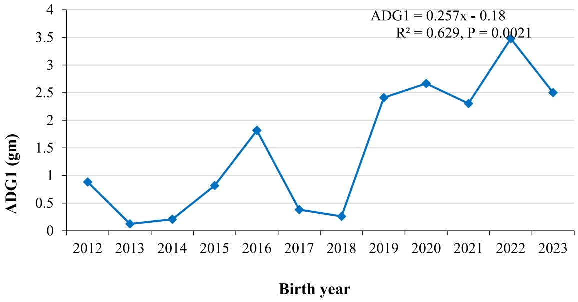

Fig. 4. Genetic average daily gain trend by year of birth.

heritability values for WT0 was in accordance with estimates of [3], in Dorper sheep (0.12 ± 0.03). Permanent environmental heritability estimates for WT0 (0.13 ± 0.04) was lower than that reported by Ref. [29], in Sabi sheep (0.08 ± 0.03). Opposing to the present finding, the higher permanent environmental heritability for WT0 was reported by Ref. [45], in Moghani sheep (0.20 ± 0.04) and by Ref. [44], in Iran-Black sheep (0.31 ± 0.02).

Fitting permanent and maternal genetic effects in the Model in WT3, WT6, WT12, ADG0-3, ADG3-6, KR1 and KR2 had no

Table 3
Variance components and heritability estimates for Dorper sheep.

Traits	M	h_a^2	h_m^2	c^2	h_t^2	r_{am}	σ_a^2	σ_m^2	σ_c^2	σ_e^2	σ_P^2	σ_{am}	Log (L)
WT0	**2**	0.07 (0.06)		0.13 (0.04)	0.07 (0.06)		0.037		0.068	0.397	0.502		−204.62
WT3	**1**	0.11 (0.06)			0.11 (0.06)		1.279			10.455	11.734		−1309.77
WT6	**1**	0.09 (0.07)			0.09 (0.07)		2.088			20.758	22.846		−1129.48
WT12	**1**	0.11 (0.09)			0.11 (0.09)		3.406			26.886	30.292		−990.875
ADG0-3	**1**	0.11 (0.06)			0.11 (0.06)		141.11			1186.09	1327.20		−3026.358
ADG3-6	**1**	0.00 (0.04)			0.00 (0.04)		0.001			1233.19	1233.191		−2186.071
KR1	**1**	0.15 (0.07)			0.15 (0.07)		0.704			3.826	4.530		−959.304
KR2	**1**	0.00 (0.04)			0.00 (0.04)		0.001			9.992	9.993		−913.957

σ_P^2: phenotypic variance, σ_a^2: additive variance, σ_m^2: maternal variance, σ_c^2: common environment variance, σ_e^2: error variance, h_a^2: direct heritability, h_m^2: maternal heritability, c^2: ration of common environment variance to the total phenotypic variance, h_t^2: total heritability, r_{am}: genetic correlation between direct and maternal additive heritability, σ_{am}: covariance between direct and maternal additive genetic effect, Log (L): log Likelihood, WT0-WT12: weight at birth, three months, six months and yearling age, respectively, ADG0-3: average daily gain from birth to weaning, ADG3-6: average daily gain from weaning to six months, KR1: Kleiber ratio birth to weaning, KR2: Kleiber ratio weaning to six months.

significant effects in log-likelihood values compared to Model 1, which indicates insignificant effect of permanent and maternal genetic effects on those traits. Direct heritability estimates with appropriate models (Model 1) for WT3, WT6, WT12, ADG0-3, and ADG3-6 were low in magnitude. Contrary to the present finding, the higher direct heritability estimates for WT3, WT6, WT12, ADG0-3, and ADG3-6 was reported for different sheep breeds [42–44], using same model. The low direct heritability estimates for the studied traits can be explained by the low genetic diversity of the flock, low nutritional management and low quality of grazing pastures, which result in a high environmental variance [37]. Direct heritability estimates for KR1 (0.15 ± 0.07) obtained in this study was in close agreement with those found by Ref. [30], in Sanjabi sheep (0.15 ± 0.06) and by Ref. [36], in Sangsari sheep (0.13 ± 0.04). However, higher estimates of direct heritability for KR2 was reported by Ref. [30], in Sanjabi sheep (0.07 ± 0.05). Lower estimates of direct heritability for KR1 was reported by Ref. [39], in Arman sheep (0.04 ± 0.03). Literature estimates of direct heritability have revealed that the Kleiber ratio is low heritable traits [29,35]. The low heritability estimate in these traits indicates difficulty in improving genetic gain by applying selection on these traits.

Table 4
Correlation estimates among body weight traits.

Trait 1	Trait 2	r_{p12}	r_{d12}	r_{e12}
WT0	WT3	0.28 ± 0.05	0.20 ± 0.18	0.34 ± 0.08
WT0	WT6	0.24 ± 0.05	0.23 ± 0.18	0.25 ± 0.08
WT0	WT12	0.21 ± 0.06	0.24 ± 0.19	0.20 ± 0.10
WT0	ADG0-3	0.09 ± 0.06	0.04 ± 0.19	0.13 ± 0.09
WT0	ADG3-6	0.04 ± 0.05	0.14 ± 0.22	−0.01 ± 0.08
WT0	KR1	−0.31 ± 0.05	−0.39 ± 0.16	−0.24 ± 0.09
WT0	KR2	−0.09 ± 0.06	−0.06 ± 0.22	−0.12 ± 0.09
WT3	WT6	0.85 ± 0.01	0.90 ± 0.04	0.80 ± 0.03
WT3	WT12	0.52 ± 0.05	0.54 ± 0.16	0.49 ± 0.10
WT3	ADG0-3	0.98 ± 0.01	0.99 ± 0.01	0.97 ± 0.01
WT3	ADG3-6	0.14 ± 0.05	0.19 ± 0.22	0.14 ± 0.09
WT3	KR1	0.80 ± 0.02	0.81 ± 0.06	0.79 ± 0.04
WT3	KR2	−0.21 ± 0.06	−0.22 ± 0.20	−0.21 ± 0.10
WT6	WT12	0.72 ± 0.03	0.74 ± 0.10	0.71 ± 0.06
WT6	ADG0-3	0.83 ± 0.02	0.88 ± 0.05	0.78 ± 0.04
WT6	ADG3-6	0.65 ± 0.03	0.59 ± 0.15	0.69 ± 0.05
WT6	KR1	0.68 ± 0.03	0.72 ± 0.09	0.66 ± 0.06
WT6	KR2	0.30 ± 0.06	0.19 ± 0.21	0.39 ± 0.09
WT12	ADG0-3	0.49 ± 0.05	0.51 ± 0.16	0.47 ± 0.11
WT12	ADG3-6	0.60 ± 0.04	0.68 ± 0.13	0.57 ± 0.07
WT12	KR1	0.41 ± 0.06	0.42 ± 0.16	0.38 ± 0.12
WT12	KR2	0.28 ± 0.07	0.24 ± 0.22	0.33 ± 0.12
ADG0-3	ADG3-6	0.14 ± 0.05	0.17 ± 0.22	0.12 ± 0.09
ADG0-3	KR1	0.89 ± 0.01	0.90 ± 0.04	0.89 ± 0.02
ADG0-3	KR2	−0.20 ± 0.06	−0.21 ± 0.20	−0.19 ± 0.11
ADG3-6	KR1	0.13 ± 0.06	0.13 ± 0.21	0.14 ± 0.10
ADG3-6	KR2	0.86 ± 0.02	0.84 ± 0.08	0.87 ± 0.03
KR1	KR2	−0.16 ± 0.06	−0.17 ± 0.20	0.57 ± 0.12

r_{p12}: phenotypic correlation between trait 1 and 2; r_{d12}: direct genetic correlations between traits 1 and 2; r_{e12} residual correlations between traits 1 and 2; WT0-WT12: weight at birth, three months, six months and yearling age, respectively; ADG0-3: average daily gain from birth to weaning; ADG3-6: average daily gain from weaning to six months; KR1: Kleiber ratio birth to weaning; KR2: Kleiber ratio weaning to six months.

3.3. Correlation estimates

Genetic, phenotypic and environmental correlations among the studied traits are shown in Table 4. Genetic correlations among studied traits were ranging from low (−0.39) for WT0-KR1 to high (0.99) for WT3-ADG0-3 while phenotypic correlations changed from −0.31 for WT0-KR1 to 0.98 for WT3-ADG0-3. Negative genetic correlations between WT0-KR1 (−0.39), WT0-KR2 (−0.06), WT3-KR2 (−0.22), ADG0-3-KR2 (−0.21), and KR1-KR2 (−0.17) were found. It can be concluded that lambs with higher growth rate and Kleiber ratio during pre-weaning period have less efficient during the post-weaning period and vice versa. Existence of unfavorable genetic relationships between those traits denotes that different genetic mechanisms are involved in the expressing those traits in genetic level at different stage of growth [22,46]. Similarly [30], founds similar correlation estimates to the current study. With the exception of observed negative correlation between WT0-KR1, WT0-KR2, and WT3-KR2, genetic and phenotypic correlation of WT0, WT3, WT6 and WT12 with others studied trait were positive and weak to high in magnitude. The genetic and phenotypic correlation estimates of −0.19 and −0.39 for WT0-KR1 was similar to the estimates of [46], in Lori sheep. Furthermore genetic and phenotypic correlation estimates of −0.22 and −0.21 for WT3-KR2 was comparable to the finding of [30], in Sanjabi sheep. Higher estimates of genetic and phenotypic correlation for ADG0-3-KR1 and ADG3-6-KR2 were in consistence with those obtained by Ref. [47], for Horro sheep and [30], in Sanjab sheep. High genetic and phenotypic correlation estimates of 0.90 and 0.85 for WT3-WT6 was comparable to the finding of [30,46,48], in various sheep breed, whereas lower estimates was reported by Refs. [22,37,39], in different sheep breed. The high genetic correlation between WT3 and WT6 (0.90) indicated that selection in one of these traits will have a high genetic change on the other one.

3.4. Annual genetic trends and inbreeding coefficient

The genetic trends for WT3, WT6 and WT12 showed a positive improvement trends a rate of 0.029, 0.043 and 0.049 kg over years respectively (Fig. 3). Furthermore, ADG0-3 and KR1 showed improvement trend a rate of 0.257 g and 0.016 over years respectively (Figs. 4 and 5). The genetic trend for the traits under study, as determined by fitting a linear regression of the yearly mean EBV on the year of birth, showed a significant difference ($P < 0.01$). The genetic trends for WT3, WT6, WT12 and ADG0-3 declined between the year 2012–2013, 2017–2018 and 2020–2021 followed by an improvement trends. The genetic trend for KR1 declined between the year 2012–2014 and 2016–2018 followed by improvement trend. Difference in feed availability, climatic conditions and poor selection of breeding rams, are the possible cause for the declined trend of EBVs during these years. The positive genetic improvement trends of the studied traits as compared to the phenotypic performance indicated that performance of the breed was greatly influenced by management and climatic conditions such as disease, parasite load and availability of grazing pasture. This result also indicated poor human intervention to develop improved forage though irrigation or other means. [18], reported higher genetic trend for WT3 and WT12 for Dorper sheep (0.096 and 0.163 kg respectively). The average inbreeding coefficient was 0.84 % with average inbreeding rate of 0.166 % (Fig. 6). The average annual inbreeding trend by fitting linear regression was significantly different from zero ($P < 0.0001$). The average inbreeding coefficient in the flock is under acceptable ranges. Inbreeding coefficient recorded under the present study was lower than the critical of 6.25 % [49]. Moreover, the level of inbreeding recorded in the current study is lower than the Food and Agricultural Organization of the United Nation (FAO) recommendation that the annual inbreeding rate should be maintained below the range of 0.5–1 % to avoid the risk of genetic disorders and inbreeding depression [50].

4. Conclusion

The study confirmed a decline in the phenotypic trend over the years, while the genetic trend for the traits showed an increase. The observed decline in phenotypic performance can be attributed to changes in station management practices over the years. Specifically, the transition from grazing to indoor feeding on dry roughages, which was implemented to control fasciolosis infestation, may have played a role. These changes in management practices have resulted in deficiencies in crucial vitamins and minerals, including vitamin E and selenium. These deficiencies can have a negative impact on various aspects of the sheep's well-being, such as growth, reproduction, and immune response. Consequently, these factors contribute to the reduction in phenotypic performance that has been observed. Model including direct genetic effects as well as permanent environmental effect (Model 2) was chosen as the most appropriate model for WT0. Model which included only direct genetic effects (Model 1) was the best-fit model for WT3, WT6, WT12, ADG0-3, ADG3-6, KR1 and KR2. The low direct heritability estimates for the studied traits indicated that genetic improvement by direct selection might be difficult. The high genetic correlation among weaning and six month weight indicated that selection for one of these traits would bring out a positive response for other trait. Further investigation for the unexpected declined trend of phenotypic performance over years need to be required.

Ethical approval

Review and/or approval by an ethics committee was not needed for this study because we do not conduct animal experiment. We only used data collected from animals used for breeding purposes.

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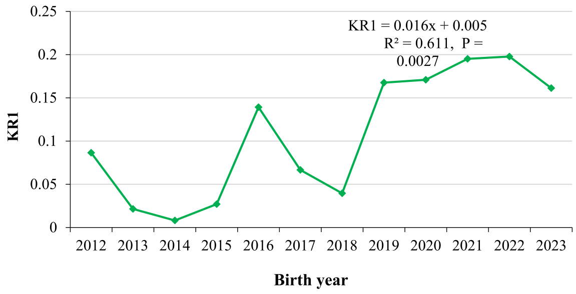

Fig. 5. Genetic kleiber ratio trend by year of birth.

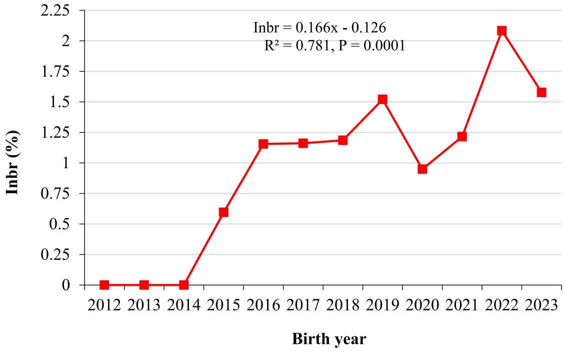

Fig. 6. Inbreeding trend by year of birth.

Institute (ARARI) and Ethiopian Institute of Agricultural Research (EIAR).

Data repository statement

Debre Birhan Agricultural Research Center (DBARC) does not have an official repository, so the data is not available in the public repository, but it is available in soft copy at the center.

Data availability statement

Data will be made available on request.

CRediT authorship contribution statement

Shanbel Besufkad: Writing – review & editing, Writing – original draft, Software, Project administration, Formal analysis, Data curation. **Shenkute Goshme:** Visualization, Project administration, Data curation. **Asfaw Bisrat:** Visualization, Project administration, Data curation. **Aschalew Abebe:** Visualization, Project administration, Data curation. **Ayele Abebe:** Visualization, Project administration, Data curation. **Tesfaye Getachew:** Writing – review & editing, Validation, Project administration, Data curation, Conceptualization. **Alemnew Areaya:** Visualization, Project administration, Data curation. **Tesfaye Zewdie:** Visualization, Project administration, Data curation. **Solomon Gizaw:** Writing – review & editing, Validation, Project administration, Data curation, Conceptualization.

Declaration of competing interest

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

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