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Original Paper

Phenotypic and Genetic Parameter Estimation of Milk Traits of Abergelle Goat in Ethiopia

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***Abstract*— This study aimed to evaluate the production performance and genetic parameters of Abergelle goat milk traits in Addis Mender and Alquzu village, Wag-Himra, Amhara region, in Ethiopia. Data on milk traits were collected from 2018 to 2023 by the Sekota Dryland Agricultural Research Center from farmer-managed goats in scale-up villages. The General Linear Model (GLM) in SAS was used to analyze phenotypic traits, while Wombat software estimated genetic parameters and breeding values. Milk traits analyzed included daily milk yield (ADMY), 90-day lactation yield (LMY90 days), and lactation length (LL). Fixed effects considered were dam parity, year of kidding, and season. Mean values for ADMY, LMY90 days, and LL were 302.6±6.68 g, 28.003±47.45 kg, and 9.4±0.23 weeks, respectively. Heritability estimates for ADMY, LMY, and LL were 0.08±0.005, 0.16±0.034, and 0.04±0.034, while repeatability estimates were 0.50, 0.23, and 0.06, respectively. These findings show moderate variation in milk production traits within the population, suggesting selection as an effective tool for genetic improvement. The study highlights the importance of repeated measurements and fixed effects in designing a genetic improvement program for Abergelle goats. Results provide valuable baseline data for enhancing milk production traits in this breed.**

Keywords*— *Abergelle goats, Genetic parameters, Lactation length, Milk yield, Repeatability

I. INTRODUCTION

Goat milk plays a crucial role in the global dairy industry and is valued for its unique nutritional profile and adaptability to diverse environments. It provides essential nutrients, particularly in regions with limited resources, and offers advantages in digestibility and health benefits compared to cow milk [1]. Enhancing goat milk production involves understanding its genetic and phenotypic traits, which is an important tool for improving milk yield and quality [2].

Goat milk production is influenced by factors such as breed, feeding practices, and environmental conditions. Functional genomic tools like genome-wide association studies (GWAS) have identified critical genetic markers linked to milk traits, including casein and DGAT genes. These discoveries help optimize breeding strategies and increase milk yield while maintaining quality standards [3]. Additionally, advancements in proteomics and metabolomics have deepened our understanding of milk composition and its regulation.

Estimating genetic parameters for milk production traits such as heritability and genetic correlations leads to selection programs. Recent studies highlight heritability estimates ranging from moderate to high (0.27–0.48); suggesting significant genetic contributions to these traits [4] Molecular tools like random regression models and marker-assisted selection have refined the accuracy of these estimations, enabling targeted breeding for desirable traits.

Future research should focus on integrating multi-comics data, expanding genetic studies to underrepresented populations, and exploring epigenetic influences, which will support sustainable genetic improvements in goat milk production [5].

The Abergelle goat breed, a valuable genetic resource in Ethiopia, plays a crucial role in supporting livelihoods through milk production. However, limited research exists on the phenotypic and genetic parameters influencing milk yield and quality in this breed. Understanding these parameters is essential for developing effective breeding programs and improving productivity. The lack of such data hinders targeted interventions and sustainable genetic improvement efforts. This study aims to estimate the phenotypic and genetic parameters of goat milk traits, addressing critical gaps in knowledge for the Abergelle breed.

II. Material And Methods

A. Description of the Study Area and Flock Management

The study was conducted on the farm by the Sekota Dryland agricultural research center in Addis Mender and Alquzu village in the Sekota and Ziquala districts respectively. Sekota and Ziquala districts were found in the Wag-Himera zone in the Amahara region in the northern parts of Ethiopia.

Sekota district is located 720 km away from Addis Ababa and 430km from Bahir Dar, the capital city of the Amhara Region at an altitude of 2200 m.a.s.l and at 12o 41' 11.92" N and 39°00' 58" E. Annual rainfall ranges between 350 - 700 mm, falling mainly from July to September. The pattern and distribution of the rainfall is erratic and uneven. Average temperature ranges from 16-270C (SDBOA, 2020). The vegetation can be characterized as being semi-arid shrubs dominated by various Acacia species with a sparse ground cover of annual grasses. The district is characterized by a long dry season lasting from October to June [6].

Ziquala district is located at 12º48´41.39″N and 38º43´22.02″E 775 km Northeast of Addis Ababa, Ethiopia. The district has rugged topography characterized by mountains, steep escarpments, and deeply incised valleys. A mixed crop-livestock system with a high priority on livestock production is the major farming practice in the area. The mean annual rainfall of the area was 250-650 mm with very short and erratic distribution from early July to late August. The mean annual temperature was 25-39 °C and an altitude of 1308 m.a.s.l. Based on the above agro-meteorological data and feed availability, the area was considered wet from June to November and the remaining months as dry season [7].

In the Sekota and Zequla districts, in respective villages, Addis mender and Alquzu scaling up of CBBP was established in 2018 on the Abergelle goat breed. Recording of performance data and selection of breeding bucks were implemented for six consecutive years (2018-2023). During the selection of breeding bucks, the participation of farmers and interest, the economic weight given to their animal in terms of trait when selecting breeding animals' growth; milk yield, color, and appearance of the animal were considered. The breeding objective and trait preference of farmers were studied by [8]. The established Scale-up CBBP villages which are Addis Mender and Alquzu had 40 and 36 farmers involved in each village respectively.

Milk production data of Abergelle goats collected from 2018 to 2023 from Addis Mender and Alquzu villages in Sekota dry land agricultural research center were used. Flocks were not managed based on age, sex, breed, and physiological status of the animal. Kids after birth had free access to suckle their dams for 7 days to consume enough colostrum. Then kids were separated from their dams and allowed to partially suckle (two teats) at milking times until the weaning age of 3 months. Doe was hand-milked (two teats) twice a day at about 6:00 AM and 4:00 PM. The total milk yield produced per day was calculated by doubling the daily milk yield. Data source and management Milk data (daily milk yield, lactation milk yield, and lactation length) collected and recorded in the flock book from 2018 to 2024 were used. The data were filtered and organized using Microsoft Excel. Records with no pedigree information were removed during data cleaning. Statistical analysis the data were analyzed using the General Linear Model (GLM) procedures of the Statistical Analysis System (SAS 9.0). Dam parity, kidding year, and season were the main fixed effects considered. WOMBAT software [8] was used to estimate the genetic parameters of heritability, repeatability, and genetic and phenotypic correlation. The statistical model used for the analysis of least squares means of milk traits was:

$$Yijk = \mu + Yi + Sj + Pk + e\ ijk \quad \text{.............................}(1)$$

Where:

Yijk = The observation on daily milk yield (DMY), lactation milk yield (LMY), and lactation length (LL)

μ = Overall mean,

Yi = fixed effect of ith calving year (2018-2023)

Sj = fixed effect of jth calving season (dry, wet)

Qk = fixed effect of kth parity (1-7)

eijk = effect of random errors associated with each observation.

The model used to estimate variance components and heritability of milk traits was as follow:

$$Y = Xb + Za + Wpe + e \quad \text{...}(2)$$

Where, Y is the vector of observations of the traits (DMY, LMY, and LL), b is the vector of fixed effects, a is the vector of solutions for the coefficients of direct animal (additive) genetic effects, pe is the vector of solution for permanent environmental effects and e is was the vector of residual effects. X, Z, W are the correspondent incidence matrices of the fixed effects, additive genetic and permanent environmental random effects, respectively.

The heritability and repeatability were computed as follows:

$$h2 = \frac{\sigma a2}{\sigma p2} \quad \text{..}(3)$$

and

$$r = \sigma a2 + \frac{\sigma pe2}{\sigma p2} \quad \text{...}(4)$$

Where: h2 is heritability, r is repeatability, σa2 is direct additive genetic variance, σpe2 is permanent environmental variance related to repeated records and σp2 is phenotypic variance [9]. The genetic trends for milk traits were estimated by averaging the estimated breeding value estimated by year of birth. The pedigree information and the descriptive statistics are presented in Table I.

TABLE I. Description Of Data Set For Growth And Milk Traits

No of records	ADMY	MY90(kg)	LL(days)
Number of records	1527	1527	1527
Sires with records & progeny	32	32	32
Dams with records & progeny	404	404	404

Maximum	540	46	68
Minimum	105.4	8.4	25
Mean	346	28.5	62
SD	27	16	32.4
CV	14	26	30

ADMY= average daily milk yield, MY90 days = milk yield in90 days and LL= lactation length

III. Results and Discussion

A. *The Effect of Non-Genetic Factors on Daily Milk Production Traits*

Overall least mean ADMY, MY90 Days and lactation length were 302.6±6.68 ml, 28.003±47.45 kg, and 9.4±0.23 weeks, respectively. The average daily milk yield obtained in this study was higher than the result reported for Arsi-Bale goats (209 ± 10.7 g), and lower than the report of [10, 2] for Abergelle goats (346.36 ±10.08 g). However, the current result was in line with [11] for Abergelle goats 309.0 ±8.40 ml [12] and lower than Central Highland goat breed (367.10 ±139.78 g) [13] for Boer x Central highland goats F1 crossbred (340.0±20.0 g) while it was lower than that reported by [14] for Begait goats (610±10.1 g). The greater ADMY value investigated in the current study in comparison to the previous studies for the same breed might be explained by the variations in the year of evaluation as the other scholars reported this value during the beginning two or three years of the breeding program, and currently, the overall phenotypic and genetic trends of the program are changing each year. In addition, the effect of genetic improvement programs and associated management variations are also the reasons for the higher values. The result obtained in this study was not in agreement with some of the Ethiopian goat breeds. Longer lactation lengths in contrast to the current study were reported [13] for different Ethiopian indigenous goat breeds. The 90-day milk yield, which means the total lactation milk yield in this study, was lower than the values reported by various scholars [13, 14] but higher than the report [2]. The observed variations among different reports on milk production traits could be explained by differences in the genetic makeup of the breed, variability in management systems, and variations in data collection and evaluation procedures. The average daily milk yield, lactation length, and eighty-day milk yield were significantly influenced ($p<0.001$) by the location where these values are most importantly higher at Addis Mender village (ADMY and MY90Days) than the Alquzu. The lactation length was higher at Addis Mender village even though there is no scientific justification for this variation except the accuracy of data collection was more extensive and strict at Addis Mender than at Alquzu village. Higher values of milk production traits at Addis Mender Village are obvious and described elsewhere in the document for other growth performance traits due to relatively better feed availability and access to irrigation for forage development at Addis Mender. Significant variations of milk production traits by location were reported by [15] because milk production traits are significantly affected by the level of nutrition and other environmental characteristics [16], clearly described that milk productivity in goats mainly depends on the quality and quantity of feedstuffs and approaches targeting milk production improvement should first address the issue of nutrition. Year and season of birth exerted a significant effect ($p<0.05$) on ADMY, LL, and MY90Days. These traits were significantly improved across different years and the higher values were recorded in 2018 and 2019, whereas lower values were obtained in 2013 and 2014. Higher daily and 90-day milk yield production and a longer lactation length period were found during the wet season than the other. Similar other reports confirmed the effect of year and season of kidding on the milk production performance of doe [17]. The higher milk yield and longer lactation length during the wet season might be explained by the availability of better livestock feed resources than during the drier season.

The parity of doe at kidding had a pronounced influence ($p<0.01$) on all studied milk production traits in the current study. The greater values of ADMY and MY90D were attained in later parity dams (4th - 6th parity) than the earlier parity counterparts as the parity increased and the age of animals increased young animal and the edged animals milk was low [18] 4- 6 parity animals gives higher milk other than other parties [14,18,19] reported significant effect of parity on milk production traits in does while[13,19,20], documented its non-significant influence on milk traits. In general, [19] described milk yield increases with age because the hormonal status of the animal body, metabolic activity, secretory cells, and nutrient intake of the doe that are important for milk synthesis increases with its age. The authors also outlined that the significant effect of age and parity on milk traits suggests milk production tends to increase with parity probably due to an increase in the accumulation of mammary alveoli from previous lactation until the process gets interrupted by advances in age. The phenotypic trend for milk production traits of Abergelle goats managed under CBBP conditions is presented in Table II. Except for a little decline in lactation length in 2020, all other traits showed a positive trend. This could be explained by the effect of selection on improving milk productivity was going in the right direction even though it is possible to improve these traits beyond the current result through dam line selection. In General, as shown in Table II below the overall ADMY was 302.6 mL, while the lactation length averaged 9.4 weeks, and the MY90Days was 28003ml these results suggest a moderate level of milk production in Abergelle goats, compared to other breeds. Significant differences were noted between villages, Addis Mender goats showed higher ADMY (323.9 mL) compared to Alquzu (279.6 mL) this aligns with findings from [21], who also reported village-specific variations in milk yield among goat breeds. Seasonal variation in the dry season produced a lower ADMY (298.9 mL) compared to the wet season (310.7 mL) this is consistent with the work [20], which indicated that wet seasons typically enhance milk production due to better forage availability. Year as the trends of milk production showed fluctuations across the years, with 2019 recording the highest ADMY (308.01 mL) these trends were also noted by [22], who emphasized the impact of environmental and management factors on yearly milk yields. Parity The data revealed that goats in their second and fifth parity had significantly higher ADMY (304.16 mL and 315.48 mL, respectively) compared to the first parity (281.97 mL), this finding corroborates the research by [23] which highlighted increased milk production in older goats due to experience and physiological maturity. Disagreements with Other Studies Contradictory Findings on Parity: While this study found that parity 3 had the highest

ADMY, other studies, such as those by [24], suggest that parity 4 often yields the best results, indicating a potential discrepancy in findings. Seasonal Impact on Lactation The current study shows a more pronounced effect of dry versus wet seasons on lactation length compared to the findings of [25], who reported minimal seasonal effects.

From the above discussion, this study measured milk production traits in Abergelle goats, revealing an average daily milk yield (ADMY) of 302.6 mL, a 90-day milk yield (MY90) of 28.003 kg, and a lactation length of 9.4 weeks. The ADMY was higher compared to Arsi-Bale goats but lower than that of Abergelle goats from other studies. Variations in these results were attributed to factors such as the year of evaluation, genetic improvements, and management practices. Additionally, the study found significant differences in milk production based on location, with goats in Addis Mender showing higher yields than those in Alquzu, likely due to better feed availability and irrigation in the former.

The study also examined the influence of year and season on milk production traits. Significant improvements were noted in ADMY, lactation length, and MY90 days in 2018 and 2019, with higher milk yields during the wet season. These findings align with other research showing that better feed resources in the wet season contribute to improved milk production. Furthermore, the parity of does at kidding significantly influenced milk production, with older does (4th to 6th parity) yielding higher ADMY and MY90 compared to younger does. This supports previous research suggesting that milk production increases with age due to hormonal and metabolic changes. The study shows that Abergelle goats have moderate milk production, with improvements over time, village-specific variations, seasonal effects, and inconsistent findings regarding the impact of parity.

TABLE II. LEAST SQUARE MEANS (LSM±SE) FOR MILK PRODUCTION TRAITS OF ABERGELLE GOAT

Source of variation	N	ADMY(ML) LSM±SE	N	LL(weeks) LSM±SE	N	MY90Days (ML) LSM±SE
Overall	1527	302.6±6.68	1527	9.4±0.23	1527	28003±47.45
CV		35.5		40.2		54.9
Village		***		***		***
Addis mender	790	323.9±3.74[a]	790	10.6±0.12[a]	790	33918±50.21[a]
Alquzu	727	279.6±3.90[b]	727	8.06±0.13[b]	737	21663±51.99[b]
Season		*		*		**
dry	1036	298.9±3.34[b]	1036	9.2±0.1[b]	1042	270228±47.45b
Wet	481	310.7±4.90[a]	481	9.7±0.1[a]	485	301102±69.56a
Year		NS		***		*
2018	254	290.3±6.752	254	10.2±0.23[a]	254	296368±96.03[ab]
2019	214	308.01±7.35	215	10.3±0.25[a]	215	311794±104.3[a]
2020	259	301.6±6.68	262	9.3±0.23[b]	262	280378±94.5a[bc]
2021	308	302.8±6.13	310	8.9±0.21[b]	310	26.0243±86.9[c]
2022	482	307.3±4.90	486	8.9±0.16[b]	486	269886±69.4[bc]
2023	482	307.3±4.90	486	8.9±0.16[b]	486	269886±69.4[bc]
Parity		**		***		***
1	48	281.97±15.48[d]	50	5.6±0.52[c]	50	149350±213.9[e]
2	276	304.16±6.46[b]	278	9.3±0.22[b]	278	275662±90.7[d]
3	245	310.23±6.85[a]	247	9.8±0.23[a]	247	303796±96.2[a]
4	315	288.30±6.04[c]	315	9.5±0.20[b]	315	27275±85.2[c]
5	252	315.48±6.76[a]	255	9.6±0.23[a]	255	294398±94.7[b]
6	181	306.32±8.73[b]	182	9.6±0.27[b]	182	295947±112.1[b]
≥7	175	306.04±7.97[b]	151	9.5±0.30[b]	151	288112±123.1[c]

***, p<0.001; **, p<0.01; *, p<0.05; ns, p>0.05; N, number of observation ADMY, average daily milk yield; LL, lactation length; MY 90 Day

B. *Heritability Estimates for Milk Production Traits*

Estimated heritability and repeatability for ADMY, LL, and MY90 days are shown below in Table II. The direct heritability estimates for ADMY, MY90 days and LL was 0.08±0.050, 0.04±0.034, and 0.16±0.034 respectively. The repeatability average daily milk yield in 90 days and lactation length were 0.503967, 0.062615, and 0.22617 respectively. The estimated heritability and repeatability for all milk traits in the present were low. This implies that low heritability and repeatability in production milk traits had no significant effect in this work. The heritability estimates from the present study were comparable with the following reports. For Arsi-Bale goat reported by [1] which is 0.03, 0.69, and 0.071 for lactation length, lactation milk yield, and daily milk yield respectively. However, the present study was lower than the report of [26], for Jamunapari goats in semiarid tropics which is 0.15±.05, 0.26±0.07 and 0.02±0.03 for milk yield in 90 days, total milk yield, and lactation length respectively. Heritability of Milk Yield (ADMY and LMY), Heritability for milk yield is generally considered to be low to moderate in dairy animals. Our results of 0.08 for daily yield and 0.16 for lactation yield are within the ranges reported in many studies. Several studies have reported heritability ranging from 0.10 to 0.40 for milk yield [27]. The variability may be due to differences in breeds, and populations, and disagree with some of the studies show higher heritability for LMY around 0.25 - 0.30 or higher in different breeds of animals, which could indicate that the specific populations in those studies had more additive genetic variation or different environmental impacts. Heritability of Lactation Length (LL) was very low heritability reported here (0.04) is consistent with findings in the literature that consistently show low heritability of lactation length [28, 29]. This suggests that lactation length is influenced more by management and environment than by genetics. The variability in reported heritability for lactation length, albeit generally low, could be explained by differences in how lactation length is defined (fixed or voluntarily ended by farmers) across studies and populations. The parameter estimates for milk yield and lactation length are presented in Table III. The estimates of direct additive heritability for ADMY and TMY were low to moderate and ranged from 0.11704 to 0.0871 (Table III). The maternal variance contributed significantly to TMY and was low for MY90. The permanent environmental component due to animals and litter contributed negligibly. The heritability estimates across different traits were significantly ($P<0.05$) different from zero with small standard errors (varies from 0.1800 to 0.2976). This is mainly because of the large sample size and indicating that the genetic improvement by selection for milk production for average daily milk yield and 90 days is likely to be successful. The heritability estimates from the present study were comparable with the following reports in the literature [30, 31, 32, 33, and 34]. [30] Reported heritability estimates of 0.29 to 0.39 for milk yield in French Alpine and Saanen primiparous goats and [31] reported heritability estimates for milk yield in Alpine goats from 0.34 to 0.37 and in Saanen from 0.32 to 0.40 in France. [32] Reported heritability estimates of 0.23 for milk yield of South African Saanens. [33] Estimated heritability estimates of 0.19 for milk yield in Alpine, Toggenburg, Saanen, and Nubian breeds. [35] Estimated heritability for first-parity milk yield of US dairy goats as 0.36 across breeds, which varied within breed from 0.35 to 0.38. Similarly, low to moderate estimates of heritability (0.17 to 0.30) for milk yield in Saanen goats were reported in central Mexico [36, 37].[38] also reported heritability of 0.30 for US Alpines and Saanens for the first lactation yield. Low heritability estimates of 0.04 for lactation length were reported by [35] in Saanen goats reared in Mexico. We also obtained low estimates of heritability for LL. The heritability estimates from our study were lower than those reported in other goat breeds, 0.68, 0.61, and 0.54 for Alpines, Saanens, and Toggenburg, respectively [39].Repeatability estimates for all milk production traits were high ranging from 0.503967 and 0.22617 for average daily milk yield and TMY, respectively. The repeatability of milk production traits was higher than those reported in the literature [41, 42]. [41] Estimated the heritability of 0.32 and a repeatability of 0.53 for the milk yield of French Alpines. [41] Reported heritability estimates of 0.35 (repeatability of 0.52) for daily milk yield in New Zealand Saanens goats. The additive maternal genetic effects were low and only important for TMY. This may be due to the environmental influence of dams on their kids from conception to birth via intrauterine environment and from birth to 3 months of age via maternal colostrum feeding and milk suckling. Maternal genetic effects have been described in domestic mammals such as swine [43] and beef cattle [43].

The pattern of higher residual variance compared to additive genetic variance is commonly seen in dairy production traits, as they are greatly influenced by environmental factors (nutrition, health, management, etc.) for Specific values. The actual values of genetic, permanent environmental and residual variance differ across studies based on the specific breed, geographical location, period, and methodological approach used in each study. The lower estimated values for all milk production traits obtained in this study compared to other work might be explained by various factors such as environmental differences, data size and quality, modeling techniques, and time frame variations. Data quality is mentioned as a potential factor influencing the estimates, indicating that data collected under on-farm conditions may be subject to measurement and technical errors compared to data collected under more controlled conditions. Generally, the heritability estimates suggest low heritability for milk production traits in Abergelle goats under the CBBP scale-up village. However, the estimates are influenced by various factors, including environmental conditions and data quality. Further research may be needed on stations with long generation intervals to refine these estimates and better understand the genetic basis of milk production traits in Abergelle goats, potentially informing more effective breeding strategies to improve milk yield in this population.

TABLE III. VARIANCE COMPONENTS AND GENETIC PARAMETERS FOR MILK TRAITS

Trait	ADMY	LL	TMY
σ^2_a	0.117	0.34	0.0871
σ^2_{pe}	4.6	0.03	2.04
σ^2_e	0.18	0.0506	0.2976
$\sigma^2 p$	0.23315	5.43	0.3851
h^2_a	0.08±0.050	0.04±0.034	0.16±0.034
LogL	-4024.4	-974.87	-1738
r	0.503967	0.062615	0.22617

ADMY = average daily milk yield, LL lactation milk yield, LMY=lactation milk yield of in 90 days

Generally, the milk production trait in genetics ADMY (average daily milk yield) is the most genetically influenced trait, with the highest additive genetic variance. However, the residual environmental variance is large, and the heritability is low, indicating that while genetics play a role, environmental factors are more influential. (Lactation length) LL has a small additive genetic variance and heritability, meaning genetic factors have a lesser role. It is also weakly correlated with the other traits. LMY (lactation milk yield) falls between ADMY and LL in terms of genetic and environmental variance, with a low heritability estimate but moderate correlations with the other traits.

As shown in table III provides an overview of how these traits behave genetically and environmentally in a population, helping inform breeding strategies, such as whether selection based on these traits would be effective in improving them. The low heritability across all traits suggests that environmental factors play a significant role and that selection for these traits may need to be supplemented with improved management or environmental conditions.

IV. CONCLUSION

In the current study; LL, the nature of the experiment, and other management conditions could be the main reasons for the underestimates of milk production in A Aberegelle goats. The highest ADMY was recorded in the kidding season in the wet season). Wet season favored goats for better milk production in the study area. The heritability of milk production traits seems high in ADMY and in lactation length (LL). This indicates that there are highly variable environmental conditions at the study site. Accurate estimates of genetic parameters are vital for genetic improvement in livestock. Although a large data set is required for more accurate parameter estimates, the results obtained in this investigation can be applied to the Abergelle goat's genetic improvement program. The results from this study on Abergelle goats provide valuable insights into milk production traits, showing both agreements and disagreements with existing literature. Further research is needed to explore the underlying factors influencing these variations and to establish more robust guidelines for goat management practices. Breeding Strategies: The heritability estimates suggest that while genetic selection is more promising for LMY, significant improvement in ADMY and LL will require careful management of environmental factors in addition to selective breeding. Environmental Management: Given the high environmental variance, implementing management practices that minimize environmental fluctuations could improve milk production consistency and predictability. Future research should focus on further exploring the environmental factors influencing milk production in Abergelle goats and refining genetic parameter estimates for more effective breeding strategies. Additionally, studies should aim to develop management practices that reduce environmental variability and enhance milk production consistency.

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