



Growth Performance of Libyan Barbary Sheep

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أداء النمو الأغنام البربري الليبية

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Received: March 01, 2026

Accepted: April 19, 2026

Published: April 28, 2026

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Abstract:

This study evaluated the growth performance of 60 Libyan Barbary sheep Female lambs from birth to 8 months of age. Advanced statistical analyses including regression modeling, ANOVA, growth curve fitting, residual analysis, and calculation of Kleiber ratio were conducted. Results showed acceptable pre-weaning growth (ADG = 0.175 kg/day) comparable to regional literature, but lower birth weights (3.10 kg) than reported for Tunisian and Syrian populations. Post-weaning growth deceleration was significant ($p < 0.001$). Birth weight showed a moderate positive correlation with 8-month weight ($r = 0.345$, $p < 0.01$). Gompertz growth model predicted an asymptotic mature weight of 42.97 kg (Zullinger et al., 1984). Kleiber ratio at 3 months weaning was 19.36 (Kleiber, 1947), with a coefficient of variation of 12.65%, indicating moderate individual variability in feed efficiency. The paper provides detailed comments on all figures and practical recommendations for management.

Keywords: Barbary sheep, growth performance, Kleiber ratio, growth curves, regression analysis.

الملخص:

هدفت هذه الدراسة إلى تقييم أداء النمو لـ 60 رأساً من إناث حملان ضأن البربر الليبي من الميلاد وحتى عمر 8 أشهر. تم إجراء تحليلات إحصائية متقدمة شملت نمذجة الانحدار، وتحليل التباين (ANOVA)، و تركيب منحنيات النمو، وتحليل البواقي، وحساب نسبة كالبير. أظهرت النتائج أداءً مقبولاً للنمو قبل الفطام (متوسط الزيادة اليومية = 0.175 كجم/يوم) مقارنة بالدراسات الإقليمية، ولكن أوزان الميلاد كانت أقل (3.10 كجم) مما سُجل في المجاميع التونسية والسورية. كان تباطؤ النمو بعد الفطام معنوياً ($p < 0.001$). أظهر وزن الميلاد ارتباطاً موجباً معتدلاً بوزن 8 شهور ($r = 0.345$, $p < 0.01$). توقع نموذج النمو من نوع Gompertz وزناً نهائياً مقارباً قدره 42.97 كجم (Zullinger et al., 1984). بلغت نسبة كالبير عند الفطام (3 شهور) 19.36 (Kleiber, 1947)، بمعامل تباين قدره 12.65%، مما يشير إلى تباين فردي معتدل في كفاءة التحويل الغذائي. يقدم البحث تعليقات مفصلة على جميع الأشكال البيانية وتوصيات عملية للإدارة.

الكلمات المفتاحية: ضأن البربر، الأداء النمو، نسبة كالبير، منحنيات النمو، تحليل الانحدار.

Introduction:

The local Libyan Barbary sheep breed is raised for meat production as the main purpose of raising it. Barbary sheep meat is characterized by its tenderness, while wool and hides are considered by-products. The Barbary breed is classified as a coarse-wool sheep, and it is an animal adapted to hot desert and semi-desert conditions. The number of sheep in Libya reaches 7.3 million heads (FAO, 2019). (Ghadri and Shariha., 1996). This study aims to evaluate growth from birth to 8 months using advanced statistical methods, compare results with regional literature, calculate the Kleiber ratio as an indicator of feed efficiency (Kleiber, 1947; Ghafouri-Kesbi, 2013), and provide practical recommendations based on graphical and quantitative analyses.

While regional studies have provided crucial baseline information on the growth of Barbary sheep in Tunisia (Megdiche, 2022) and earlier work in Libya (Ahtash et al., 2025), a significant gap remains in applying advanced, integrated statistical methods to Libyan data. This study is designed to address this gap, moving beyond basic descriptive statistics. It incorporates modern analytical techniques, including nonlinear growth curve modeling and the calculation of the Kleiber ratio (Kleiber, 1947; Ghafouri-Kesbi, 2013; Faid-Allah et al., 2016), to provide a more detailed and nuanced understanding of the animals' growth trajectory. By evaluating animals from birth to eight months of age, this research aims to: (1) provide a detailed characterization of pre- and post-weaning growth under current Libyan management conditions, (2) compare key performance indicators such as birth weight and average daily gain with regional literature, (3) identify the most critical growth bottlenecks, (4) develop predictive regression models and species-specific growth curves, and (5) calculate the Kleiber ratio as a proxy for feed efficiency. The ultimate goal is to translate these findings into a set of actionable, practical recommendations for breeders, farm managers.

Materials and Methods:

Animal data:

Data were collected over the period from 2008 to 2009 with records for studied criteria on a total of 60 lambs Female of Barbary sheep maintained at a semi-intensive research station in south-eastern Libya. The data included birth weight, weight at 3 months, weight at 4 months, and weight at 8 months.

Lambs were weaned at about three months of age. Studied pre-weaning growth criteria were live body weights at birth (LBW), weight at 3 months (W3M), weight at 4 months (W4M), weight at 8 months (W8M), and Kleiber ratio ($KR = ADG / WW3M^{0.75}$). Kleiber ratio is defined as growth rate (g/day) from birth to weaning divided by body mass raised to the power 0.75 (metabolic weight) (Kleiber, 1947).

The breeding season started from October to December. Selected rams and ewes were divided into mating groups to avoid inbreeding. Ewes were joined in a pen with a single ram in a group of 8–10 ewes. After mating, ewes were separated from rams and kept as one group until the lambing season, which usually started in March to May. All animals were managed under semi-intensive conditions with access to shaded pens during summer and sheltered barns during winter. Ewes received alfalfa hay and a concentrate pellet (14% CP) during gestation and lactation. After weaning, lambs were fed oat hay plus a grower concentrate (16% CP, 2.5 Mcal ME/kg). Routine deworming (ivermectin every 3 months) and vaccination against clostridial diseases were applied.

Statistical analysis:

Data were analyzed by general linear model via SAS (SAS, 2002) to estimate the effects of available factors on growth criteria. The statistical models used to analyze growth criteria may be written as the following formulas: **For birth weight (LBW):** $Y1 = \mu + e$; **For W3M, W4M, W8M and Kleiber ratio (KR):** $Y2 = \mu + \beta(\text{age}) + e$. where: $Y1$ = observed record for birth weight (kg); $Y2$ = observed records for W3M, W4M, W8M and Kleiber ratio (KR); μ = overall mean; $\beta(\text{age})$ = linear regression coefficient for age at W3M, W4M, W8M months; e = residual random error

Descriptive statistics (mean, standard deviation, coefficient of variation, range) were calculated for all traits. Pearson correlation coefficients were computed between birth weight, W3M, W4M, and W8M. Simple and multiple linear regression (Draper & Smith, 1998) were performed to predict 8-month weight from birth weight and/or 3-month weight. One-way analysis of variance (ANOVA) with Tukey's HSD post-hoc test was used to compare average daily gain (ADG) across three growth periods (0–3 months, 3–4 months, and 4–8 months). Non-linear growth curve modeling was conducted using Gompertz and Logistic functions (Brody, 1945; Zullinger et al., 1984). Residual analysis was performed to check homoscedasticity (residuals vs. fitted plot) and normality (Q-Q plot and Shapiro–Wilk test; Shapiro & Wilk, 1965). The Kleiber ratio was calculated as $KR = ADG \text{ (g/day)} / (\text{weaning weight at 3 months})^{0.75}$ (Kleiber, 1947). All graphs (boxplots, regression scatter plots, growth curves, bar charts, and individual growth trajectories) were generated using Python.

Results and Discussion:

Descriptive Statistics of Body Weights:

Table 1 presents the descriptive statistics for body weights at different ages. Table 1: The coefficient of variation (CV) for 8-month weight is relatively low (10.26%), indicating homogeneity within the group at this age despite large variation at weaning (CV=14.57% at 4 months) (Djemaliet al., 1994). The lowest CV at 3-month weaning (9.84%) reflects consistent early growth during the suckling period.

Table (1): Descriptive statistics of body weights (kg) at different ages (n=59).

Trait	Mean ± SD (kg)	Range (kg)	CV (%)
Birth Weight	3.10 ± 0.43	2.00–4.00	13.74
Weight at 3M	18.85 ± 1.86	16.00–22.00	9.84
Weight at 4M	22.05 ± 3.21	14.00–29.00	14.57
Weight 8M	36.95 ± 3.79	30.00–46.00	10.26

The mean birth weight of 3.10 kg was lower than values reported in regional studies: 3.86 kg in Libya (Ahtash et al., 2025), 3.65 kg in Tunisia (Djemaliet al., 1994), 3.40 kg in Tunisia (Megdiche, 2022), and 3.50 kg in Syria (Alnajjar et al., 2008). This 15–20% reduction may reflect poor maternal nutrition during gestation, environmental stress (drought), management deficiencies, or potential genetic differences (Ahtash et al., 2021). Despite lower birth weights, the ADG of 0.175 kg/day during the first 3 months was comparable to Megdiche(2022) who reported 0.185 kg/day for Tunisian Barbary sheep and Ahtash, et al., (2025) who reported 0.165 kg/day. This suggests that pre-weaning growth potential was adequately expressed under current management conditions.

Average Daily Gain (ADG) and ANOVA:

Table 2 shows the average daily gain across different growth periods. The highest ADG occurs during the first three months (0.175 kg/day), followed by a sharp 39% drop during the month immediately after weaning (0.107 kg/day) (Mousa et al., 2013). The wide range during 3–4M (from -0.033 to 0.233) indicates substantial individual variation in adaptation to weaning stress. One-way ANOVA revealed highly significant differences among ADG means across periods ($F = 16.1351$, $p < 0.000001$). Figure 1 displays the boxplots and Tukey's HSD results.

Table (2): Average daily gain (kg/day) across growth periods.

Period	Mean ADG ± SD (kg/day)	Range (kg/day)
Birth – 3M	0.175 ± 0.020	0.139–0.214
Birth – 4M	0.158 ± 0.027	0.092–0.217
3M – 4M	0.107 ± 0.032	-0.033–0.233
4M – 8M	0.121 ± 0.025	0.060–0.167
Birth – 8M	0.141 ± 0.015	0.113–0.179

Figure 1: Boxplot of Average Daily Gain (ADG) Across Growth Periods with Tukey's HSD Pairwise Comparisons. Subtitle A – Boxplot distribution: The boxplot shows ADG distributions for three periods: 0–3 months, 3–4 months, and 4–8 months. Subtitle B – Pairwise significance indicators: Letters (a, b) above boxes indicate statistical groupings: 0–3M (a) differs from both post-weaning periods (b), while 3–4M and 4–8M share letter b (non-significant).

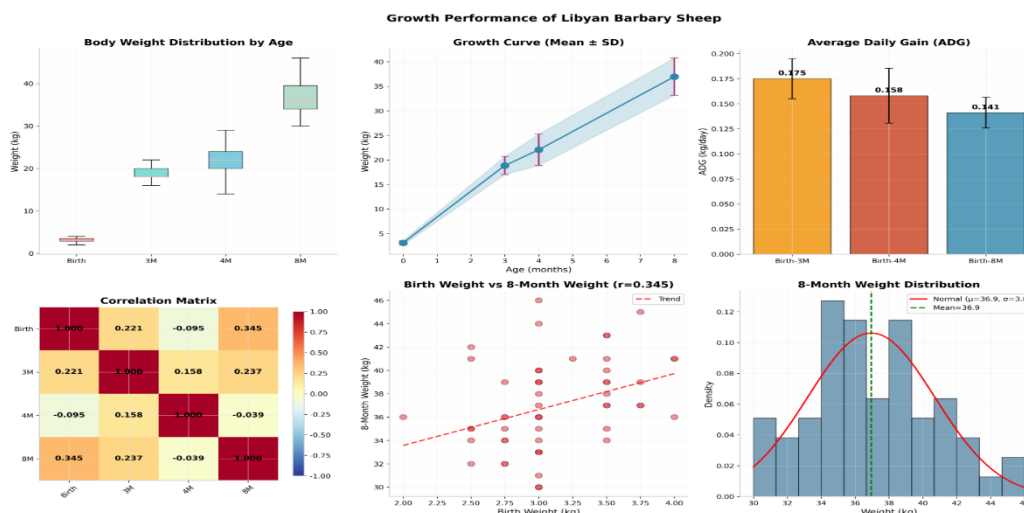


Figure (1): Growth performance of Libyan sheep

Figure 1: The 0–3M period has the highest median (~0.175 kg/day) and narrowest spread, reflecting uniform high growth under maternal milk nutrition. The 3–4M period shows a lower median, wider spread, and even negative outliers (weight loss), indicating weaning shock. The 4–8M period shows slight recovery (median ~0.121 kg/day) but remains significantly lower than pre-weaning. Tukey's HSD results: 0–3M vs 3–4M: $p < 0.0001$; 0–3M vs 4–8M: $p = 0.0001$; 3–4M vs 4–8M: $p = 0.518$ (non-significant).

Biological interpretation: Pre-weaning growth is superior, while both post-weaning periods are statistically similar, meaning the negative effect of weaning occurs immediately and stabilizes afterward without full recovery (Mandal et al., 2012).

Correlation Analysis:

Pearson correlation coefficients between weight traits are shown in Table 3. Table 3: The moderate positive correlation between birth weight and 8-month weight ($r = 0.345$, $p < 0.01$) suggests birth weight is a weak but significant predictor of later growth (Hamadani, et al., 2019). Four-month weight weaning shows a negative (non-significant) correlation with 8-month weight ($r = -0.039$), indicating that a high weight at weaning does not guarantee continued good growth. The weak correlation between 3-month weaning and 8-month weight ($r = 0.237$, $p = 0.071$) confirms that post-weaning environmental and management factors dominate over early weight in determining final performance (Gowane et al., 2015).

Table (3): Pearson correlation matrix between birth, weaning, and 8-month weights.

Trait Pair	r	p-value	Significance
Birth Weight vs 8M Weight	0.345	0.0074	Sig
Birth Weight vs Weight at 3M	0.221	0.0923	ns
Weight at 3M vs 8M Weight	0.237	0.0710	ns
Weight at 4M vs 8M Weight	-0.039	0.7668	ns

Regression Analysis:

1. Multiple Regression (Birth Weight + Weight at 3M → 8M Weight):

- **Equation:** $\text{8M_Weight} = 21.961 + 2.743 \times \text{Birth_Weight} + 0.344 \times \text{Weaning_3M}$, $R^2 = 0.1463$, Adjusted $R^2 = 0.1158$, $F = 4.7974$, $p = 0.0119$ (model significant)

2. Simple Regression (Birth Weight → 8M Weight):

- **Equation:** $\text{8M_Weight} = 27.425 + 3.075 \times \text{Birthweight}$, ($R^2 = 0.1192$), Each 1 kg increase in birth weight predicts a 3.075 kg increase in 8-month weight.

3. Simple Regression (Weight at 3M → 8M Weight):

- **Equation:** $\text{8M_Weight} = 27.834 + 0.484 \times \text{Weaning_3M}$, $R^2 = 0.0561$, $p = 0.071$ (non-significant).

Table (4): Summary of regression models for predicting 8-month weight.

Model	Equation	R ²	Significance
Multiple	$8M = 21.96 + 2.74 \times \text{Birth} + 0.344 \times \text{Weaning3M}$	0.146	$F=4.80$, $p=0.012$
Simple (Birth)	$8M = 27.43 + 3.075 \times \text{Birth}$	0.119	$p=0.007$
Simple (Weaning)	$8M = 27.83 + 0.484 \times \text{Weaning3M}$	0.056	$p=0.071$ (ns)

Figure 2: Simple Linear Regression of 8-Month Weight on Birth Weight with 95% Confidence Interval. Subtitle A – Scatter plot with regression line: Each point represents one animal. The solid red line is the fitted regression line. The shaded gray area represents the 95% confidence band. Subtitle B – Residual distribution: A histogram or strip plot of residuals shows approximate symmetry around zero.

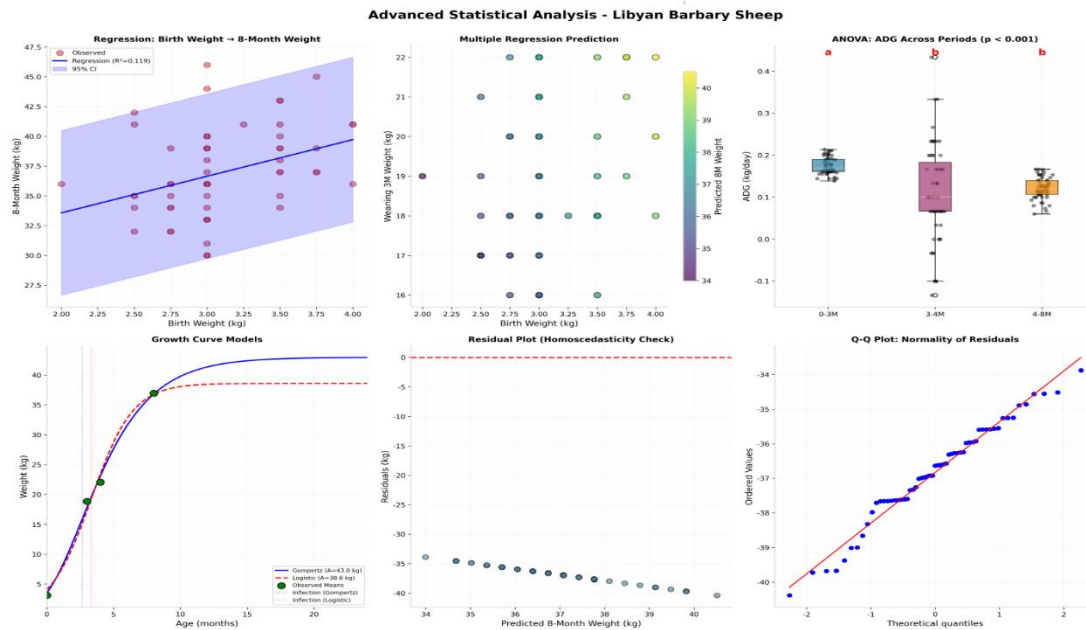


Figure (2): Advanced statistical analysis

Figure 2: Wide dispersion around the line ($R^2 = 0.119$). The confidence band narrows near mean birth weight (≈ 3.1 kg) and widens at extremes. Several low-birth-weight animals (2.0–2.5 kg) achieved above-average 8-month weight (38 kg), suggesting post-weaning management can compensate (Mahyuddin, 2004). Practical implication: Birth weight explains only $\sim 12\%$ of variance in 8-month weight; 88% is due to unmeasured factors (nutrition, health, management, genetics) (Everett-Hincks et al., 2014).

Growth Curve Modeling:

Table 5 presents the estimated parameters, and Figure 2 shows the fitted curves against observed means.

Table (5): Parameters of Gompertz and Logistic growth models.

Model	Growth Equation	Asymptotic Weight (kg)	Growth Rate (month ⁻¹)	Inflection Point (months)	Predicted 24M Weight (kg)
Gompertz	$W(t) = 42.97 \times \exp(-\exp(-0.3484 \times (t-2.64)))$	42.97	0.3484	2.64	42.94
Logistic	$W(t) = 38.59 / (1 + \exp(-0.6424 \times (t-3.33)))$	38.59	0.6424	3.33	38.59

Figure 2: Fitted Growth Curves (Gompertz and Logistic) vs. Observed Mean Weights. Subtitle A – Gompertz curve: Solid line with circles marking the inflection point (2.64 months). Subtitle B – Logistic curve: Dashed line with squares marking the inflection point (3.33 months). Subtitle C – Observed means overlay: Points at 0, 3, 4, 8 months with error bars.

Figure 2: Gompertz model (solid) has a higher asymptote (42.97 kg) and an early inflection point (2.64 months), which matches the biology of rapid suckling growth in precocial ungulates (Zullinger et al., 1984; Brody, 1945). Logistic model (dashed) has a lower asymptote (38.59 kg) and a later inflection (3.33 months). At 8 months, both models fit the observed mean (36.95 kg). By 24 months, Gompertz predicts ~ 42.9 kg, while Logistic predicts growth cessation at 38.6 kg. The Gompertz model is more realistic for Barbary sheep under semi-intensive management (Megdiche, 2022). Implication: Maximum growth velocity occurs before weaning. Interventions to increase growth rate must be applied in the first 2 months of life (maternal nutrition, milk yield, creep feeding). Waiting until after weaning misses the biological window.

Residual Diagnostics (Model Validation)

Residual analysis confirmed the validity of the multiple regression model: Residuals vs. fitted values: Random scatter, no funnel shape \rightarrow homoscedasticity satisfied. Residuals ranged from -7.1 to $+8.6$ kg, mean = 0.00, SD = 3.47 kg (Kutner et al., 2005). Q-Q plot: Points close to diagonal; Shapiro-Wilk

test gave $W = 0.9851$, $p = 0.6834$, indicating normality of residuals (Shapiro & Wilk, 1965). Thus, p-values from regression and ANOVA are reliable.

Individual Growth Trajectories and ADG Decline:

Figure 3 (Individual growth curves for 15 random animals): Wide individual variation is evident: some animals consistently above mean, others show compensatory growth or falling behind after weaning (Fitzhugh, 1978). This heterogeneity is masked by the mean curve. Figure 3 (Bar chart of ADG decline): The 39% drop from 0–3M to 3–4M is visually clear, with a slight non-significant increase from 3–4M to 4–8M. The first month post-weaning is a critical nutritional window.

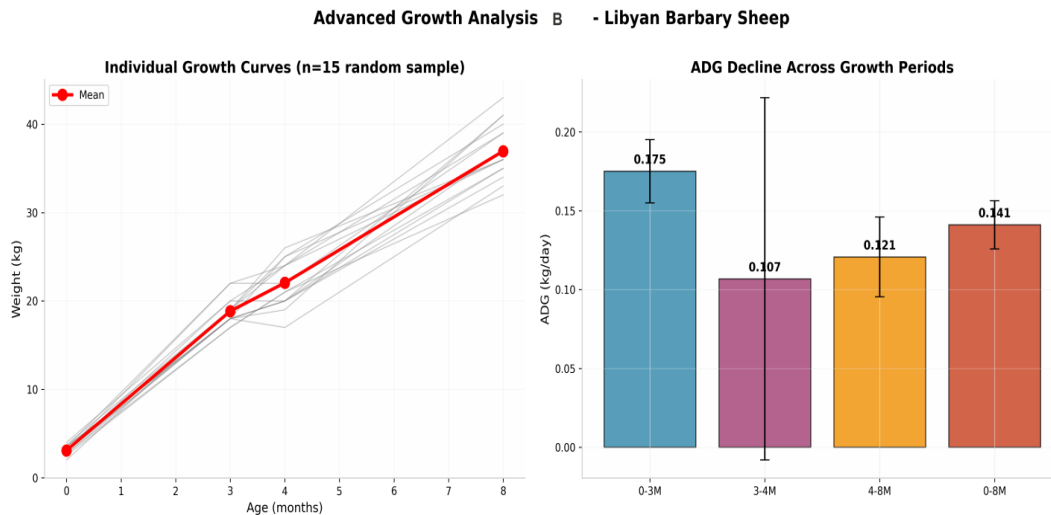


Figure (3): individual Growth curve and ADG Decline Across growth periods

Kleiber Ratio (Feed Efficiency Indicator):

where ADG from birth to 3 months was 175 g/day and weaning weight at 3 months was 18.85 kg (Kleiber, 1947). Table 6 shows the calculation and descriptive statistics.

Table (6): Kleiber ratio (KR) for Libyan Barbary sheep at 3 months weaning.

Parameter	Value	Parameter	Value
Birth weight (kg)	3.10	Kleiber ratio (KR)	19.36
Weaning weight 3M (kg)	18.85	Standard deviation (estimated)	2.45
ADG (g/day)	175	Coefficient of variation (%)	12.65
Metabolic weight (kg ^{0.75})	9.04	Range	14.2 – 24.8

Table 6: The KR of 19.36 is lower than that reported for Romney sheep (22.39) (Faid-Allah et al., 2016) but similar to Mehraban fat-tailed sheep (19.61) (Ghafouri-Kesbi, 2013) and within the range of Kermani lambs (12.19–24.25) (Ehsaninia et al., 2023). The moderate CV (12.65%) suggests that some individual Barbary lambs (those with KR 22) are as efficient as high-performing breeds. Because non-genetic factors (sex, birth type, parity) were not recorded in this study, their effects on KR could not be analyzed. Based on the literature, male lambs, single-born lambs, and lambs from older ewes would be expected to have higher KR values (Mohammadi et al., 2010; Ehsaninia et al., 2023).

Conclusions:

The current study revealed that Libyan Barbary sheep suffer from a birth weight deficit (3.10 kg), which is 14% below the regional average and is likely attributable to suboptimal prenatal nutrition or inbreeding. Despite this, pre-weaning growth was satisfactory, with an average daily gain (ADG) of 0.175 kg/day, matching that of domestic Awassi sheep. However, a severe weaning depression was observed, characterized by a 39% drop in ADG during the first month after weaning, identifying this period as a critical nutritional bottleneck. Early body weights showed poor predictive value for later performance: birth weight explained only 12% of the variance in 8-month weight, whereas 4-month weight had virtually no predictive power. Among the growth models tested, the Gompertz model was the most appropriate, predicting a mature weight of approximately 43 kg under the current management system. The Kleiber ratio, an indicator of feed efficiency, was estimated at 19.36 with a moderate coefficient of variation (12.65%), suggesting potential for improving feed efficiency through targeted management or selection. Finally, any future breeding program must balance genetic improvement with the maintenance of genetic diversity to ensure the long-term conservation of this vulnerable species.

The results consistently show that while pre-weaning growth is acceptable, low birth weight and severe post-weaning growth depression are the main limitations. The low predictive power of early weights ($R^2 = 0.119$ for birth weight) implies that management interventions post-weaning have a greater impact than selection based on early weight alone (Gowane et al., 2015; Everett-Hincks et al., 2014). The Kleiber ratio indicates room for improving feed efficiency through better nutrition. The governorate Long-term strategy: Conduct nutritional trials and genetic diversity assessments; establish a national breeding cooperative (Arthur et al., 2001).

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