Research Article

Genetic and Environmental Influences on Awassi Lamb Weights with Implications for Breeding and Management in Jordan

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Awassi sheep are well-adapted to arid climates, showcasing the potential of sheep farming in diverse and challenging environments. However, productivity remains a concern, necessitating selective breeding and improved management practices. This study, conducted at the Al-Fjaj Station in Jordan, analyzed 2,263 weight records of Awassi sheep raised under a semi-intensive system. The objective was to evaluate the environmental and genetic factors influencing lamb weight and to estimate heritability and breeding values.

Analysis of variance revealed that birth type, sex, parity, and the age of the ewe at lambing significantly affected lamb weight at all developmental stages. Single-born lambs were heavier at birth, males outweighed females, and younger ewes produced lighter lambs that exhibited compensatory growth over time. Strong positive correlations were found among weaning, six-month, and yearling weights, while birth weight had a relatively weaker influence on later weight development.

The results also indicated that individual rams had the most substantial effect on lamb weights, while heritability showed a moderate contribution. Strong genetic correlations among traits suggest that selection for one weight trait can lead to improvements in others. Breeding values tended to decline with age due to environmental influences, supporting the use of index selection to enhance desirable traits. Moreover, the strong correlations between breeding values and actual weights indicate that selecting individuals with high breeding values can enhance genetic potential and predict future performance.

Improving weight gain in future generations hinges on the selection of rams with superior breeding values. Average weight measures serve as critical indicators for both genetic progress and economic viability. This study identifies birth type, sex, parity, and ewe age as key determinants of lamb growth, highlighting the advantages of single births and male lambs. An index selection strategy that integrates both genetic and environmental factors is recommended to support sustainable lamb production in arid regions.

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1. Introduction

Ovine agriculture demonstrates remarkable adaptability across diverse environments and economic systems. However, sheep and goat farming in arid regions faces unique challenges, particularly in terms of disease prevalence, which is influenced by seasonal rainfall patterns[1]. The Awassi breed, distinguished by its fat tail and Middle Eastern origin, is especially well-suited to these dry conditions. Traditionally managed in semi-intensive systems, its adaptability has supported successful introduction into various global settings.

Enhancing the productivity of Awassi sheep in the Middle East requires a comprehensive, multifactorial approach. Key strategies include early identification of high-yielding ewes, selection for superior lamb growth rates[2], targeted nutritional support for ewes at peak reproductive age[3], strategic ram selection[4], improved prenatal nutrition, and meticulous neonatal care[5]. These integrated measures contribute significantly to overall flock performance.

Understanding environmental adaptation is vital for advancing genetic selection, particularly in arid and semi-arid zones where heat stress, water scarcity, and poor forage quality constrain productivity. Focusing on traits such as heat tolerance, disease resistance, and feed efficiency enables the development of sheep populations better suited to these harsh environments. This not only improves the sustainability and resilience of production systems but also helps preserve valuable adaptive traits in local breeds[6][7]. Integrating these environmental considerations into breeding programs is essential for developing effective, climate-resilient genetic improvement strategies.

Despite their adaptability to arid environments, Awassi sheep in Jordan face challenges such as low prolificacy and environmental and socioeconomic constraints that limit productivity[8]. While selective

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breeding has yielded improvements in both weight and milk production[9][10][11], further progress depends on a holistic strategy. This includes advanced management practices and targeted genetic selection, particularly in light of factors such as birth type, sex, ewe parity, and maternal age, which all influence lamb weight. Early weight measurements offer predictive value for later growth, and the moderate heritability of growth traits underscores the importance of strategic ram selection[12]. Enhancing lambing management and refining breeding strategies to account for both genetic and environmental influences is essential for improving growth rates in Awassi sheep[13].

At the Al-Fjaj Station in Jordan, two Awassi sheep types are maintained: the hardy local strain and a selectively bred, high-milk-producing variant[14]. This study investigates the environmental and genetic factors influencing lamb weight at key growth stages. It aims to assess the potential for genetic improvement by estimating heritability and breeding values and establishing a ranking of rams to support optimized breeding strategies.

2. Materials and Methods

2.1. Location

This study was conducted in 2023 at Al-Fjaj Station, located in the Ma'an Governorate of southern Jordan, approximately 200 km south of Amman. The station manages Awassi sheep under a semi-intensive system, making it a suitable site for evaluating factors influencing lamb weight (Figure 1). The climate in Ma'an is characterized by hot summers, with temperatures exceeding 29°C from May to September, and cool winters, with average highs below 17°C from November to March[15].

Figure 1. Map of Jordan showing Al-Fjaj Station Awassi sheep flocks in Ma'an Governorate (30.047299°N, 35.434250°E).

2.2. The sheep herd

Sheep were managed under a semi-intensive system, grazing daily even as pasture quality declined during the dry season. During the June-July mating period, selected rams naturally bred with groups of 25 ewes, yielding an average of 20 lambs per ram annually. Pregnant ewes were penned for lambing, where they nursed their lambs for the first three days. Most births occurred in October and November, with a twinning rate of 20%, primarily among ewes that had not lambed the previous year. Within 24 hours of birth, lambs were weighed, tagged, and recorded with key details, including sex, birth type, date of birth, ID, and weight.

Lambs nursed freely for the first 15 days before transitioning to controlled suckling until weaning at two months. Weights were recorded at birth, weaning, six months, and one year. Weak lambs continued suckling until they reached 14 kg. Throughout this period, lambs had free access to starter pellets and alfalfa hay.

Mature ewes grazed freely and received supplemental feed, ranging from 250-500 g per day, increasing to 0.5-1 kg in winter. Pregnant ewes were provided with 0.5 kg of alfalfa hay and 1.5-1.8 kg of concentrate daily. During dry periods, ewes were fed forage legumes and cereals, while crop residues and shrubs supplemented their diet at other times. In winter, they received a combination of concentrates, hay, and straw, with pregnant ewes receiving a specialized concentrate mix.

Lamb growth was monitored closely through scheduled weight measurements at birth, weaning, six months, and one year. Both lambs and ewes followed a controlled lactation and supplementary feeding

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program designed to optimize growth and productivity.

2.3. Data analyses

The dataset, collected between 2015 and 2023, comprised 2263 weight records from Awassi sheep, including 111 rams, 1714 ewes, and 1908 lambs. Incomplete lamb records were excluded from the analysis. Statistical analysis was performed using the General Linear Model (GLM) procedure in SAS[16], based on a fixed-effects model.

$$Y_{ijkl} = \mu + BT_i + S_j + P_k + B(X_{ijkl} - \overline{X}) + e_{ijkl} \quad (1)$$

Where, $Y_{ijk} =$ Birth weight, weaning weight, weight at 6 months, and annual weight of ijkl$^{\text{th}}$ observations. µ= overall mean. $BT_i =$ Birth type (1= Single, 2= Twins). $S_J =$ Sex of lamb (1= Male, and 2= Female). $P_k =$ Parity (1= First … 8= Eighth). B = linear partial regression coefficient of the birth weight, weaning weight, weight at 6 months, and annual weight of ijkl$^{\text{th}}$ observations on the ewe's age at lambing. X_{ijkl}= the k$^{\text{th}}$ ewe's age at lambing, $\overline{X}$ = the grand mean of the ewe's age at lambing. e_{ijkl} = random error term associated with the Y_{ijkl} observations with zero mean and variance $I\sigma^2 e$. Duncan's multiple-range test[17] was used to notice differences between means.

Partial correlation coefficients were calculated using the error sum of squares and cross-products (SSCP) matrix, with significance levels reported as Prob.>|r|. Variance components were estimated using the paternal half-sib method[18]. Subsequently, a mixed model was applied to account for both fixed and random effects.

$$Y_{ijkl} = \mu + BT_i + S_j + P_k + B(X_{ijkl} - \overline{X}) + R_{ijkl} + e_{ijkl} \quad (2)$$

Where, $Y_{ijkl} =$ Birth weight, weaning weight, weight at 6 months, and annual weight of ijkl$^{\text{th}}$ observations. $R_{ijkl} =$ Ram (i = 1, 2… 111). The prior model displays the remaining symbols and e_{ijkl} = Effect of environmental and genetic deviation related to individuals in a group of ram. Therefore, the equations are following:

$$h^2 = 4\,t, \quad t = \frac{V_S}{V_s + V_w}, \quad k = \frac{1}{s-1}\left\{N - \frac{\sum N_I^2}{N}\right\}, \quad SE\left(h^2\right) = 4\sqrt{\frac{2(1-t)^2(1+(k-1)t)^2}{k(k-1)(s-1)}} \quad (3)$$

Where, $h^2 =$ heritability value, $V_S =$ Variance component of ram, $V_W =$ Variance component of an individual, t and k are the constant, $SE\left(h^2\right) =$ Standard error of heritability, $N =$ Total number of progeny, N_i = Number of progeny per ram, and S = Number of rams.

$$EBV = \frac{N_i h^2}{4 + (N_i - 1)h^2} \left(P_{prog.} - P_{pop.}\right) \tag{4}$$

Estimated breeding values (EBV) were computed with[19].

Where, EBV = breeding value, N_i = Number of progeny per ram, h = Root of heritability value, $P_{prog.}$ = Average trait of progeny, and $P_{pop.}$ = Average birth weight of the population. The previous models show the remaining symbols.

3. Results and Discussion

Variance analysis (Model 1) revealed that birth type, lamb sex, ewe parity, and ewe age significantly influenced lamb weight traits. Birth type and parity consistently affected lamb weight across all growth stages, while lamb sex had a significant impact on birth, weaning, and yearling weights. Ewe age notably influenced weaning and six-month weights, underscoring the maternal effect on early growth.

As shown in Table 1, single-born lambs were consistently heavier than twins, and males outweighed females. Lambs born to younger ewes had lower birth weights but exhibited compensatory growth in later stages. In contrast, lambs from higher-parity ewes had higher birth weights but lower weaning weights. The greatest variability was observed in weaning and six-month weights. Overall, ewe age had a positive effect on lamb weight, particularly at the weaning and six-month stages.

Factors		Birth weights	Weaning weights	weights at 6 months	Annual weights
Overall mean (2263)		4.49±0.22	17.36±0.78	34.49±0.16	58.19±0.27
Birth Type	Single (1740)	4.55±0.03[a]	18.30±0.20[a]	35.14±0.41[a]	60.79±0.59[a]
	Twins (523)	4.02±0.04[b]	16.57±0.24[b]	32.36±0.48[b]	48.46±0.69[b]
Lamb Sex	Male (1137)	4.52±0.04[a]	17.94±0.22[a]	37.06±0.44[a]	60.09±0.62[a]
	Female (1126)	4.05±0.04[b]	16.03±0.21[b]	32.67±0.43[a]	39.16±0.63[b]
Parity	1st (802)	4.17±0.05[b]	16.82±0.26[c]	33.55±0.52[b]	56.63±0.75[c]
	2nd (421)	4.35±0.04[ab]	17.21±0.22[b]	34.52±0.44[b]	57.17±0.64[bc]
	3rd (344)	4.37±0.04[a]	17.92±0.22[a]	35.34±0.43[a]	58.00±0.62[a]
	4th (231)	4.40±0.05[a]	17.98±0.29[a]	36.49±0.58[a]	62.27±0.84[a]
	5th (188)	4.35±0.07[ab]	16.98±0.39[b]	35.01±0.78[a]	60.28±1.12[b]
	6th (158)	4.33±0.09[ab]	16.84±0.49[b]	33.11±0.97[b]	58.25±1.41[b]
	7th (80)	4.29±0.13[ab]	16.76±0.69[b]	31.56±1.36[bc]	57.93±1.97[bc]
	8th (39)	4.10±0.12[b]	16.63±0.66[c]	30.30±1.31[c]	56.45±1.89[c]

Table 1. Least square means of birth weight, weaning weight, weight at 6 months and annual weight traits/ Kg (Model 1).

The numbers in parentheses indicate the number of records. If two averages share at least one identical letter, it indicates no significant difference between them. The regression coefficients of lamb weights on ewe age at lambing are as follows: birth weight=0.023±0.002, weaning weight=0.277±0.117, 6-month weight=1.342±0.229 and annual weight=0.248±0.023. The coefficients of variation for each weight stage are birth weight=16.59%, weaning weight=19.70%, 6-month weight=19.44%, and annual weight=16.12%.

Lamb weight is influenced by multiple factors, including birth type, sex, ewe parity, and ewe age. Single-born lambs typically grow faster than twins due to better access to maternal milk, resulting in higher weaning weights. Male lambs exhibit faster growth than females due to the effects of testosterone,

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leading to higher weights at birth, weaning, and maturity. Additionally, lambs born to older ewes generally benefit from better maternal resources, achieving higher weights at all growth stages. Collectively, these factors shape lamb weight from birth through maturity (Table 1).

In arid environments, resource limitations-particularly forage and water scarcity—can hinder lamb and ewe growth. Under such conditions, survival and reproduction may take precedence over maximum weight gain, leading to adaptations such as early maturity and specialized feeding strategies[20]. Native sheep strains, genetically adapted to these harsh environments, often exhibit slower growth rates but demonstrate greater resilience to environmental stressors[21].

Table 2 illustrates positive correlations between lamb weights at various growth stages, with particularly strong associations between weaning, six-month, and yearling weights. In contrast, birth weight has a weaker influence on later weight development.

The weights (Kg)	Weaning	at 6 months	Annual
Birth	0.17**	0.07**	0.02^{ns}
Weaning		0.36**	0.33**
at 6 months			0.66**

Table 2. Partial Correlation Coefficients of birth weight, weaning weight, weight at 6 months and annual weight traits from the Error SSCP Matrix / Prob. > |r|, DF = 2251, (Model 1).

***= highly significant, ns= non-significant.*

Early lamb weight is a critical predictor of future growth, particularly at weaning, six months, and one year. Lambs that are heavier at these stages typically maintain their growth advantage, resulting in more efficient weight gain and higher overall productivity. Although birth weight has some influence, weights recorded at later stages are more reliable indicators of growth potential. This insight supports more informed management and breeding decisions, enabling the selection and nurturing of lambs with the best prospects. Ultimately, this approach enhances flock performance, productivity, and farm profitability (Table 2).

Extensive research highlights the significant role of non-genetic factors in sheep productivity. For example, the age at first lambing strongly influences the performance of Djallonke sheep[22], while Avikalin sheep show rapid early growth that later slows, emphasizing the need for effective environmental management strategies[23]. Environmental conditions are key determinants of birth and weaning weights, making early-life management essential for optimizing pre-weaning growth[24]. In high-yielding Serbian sheep, especially maiden ewes carrying multiple lambs, tailored nutritional programs are vital to ensure optimal birth weights[25].

In Pelibuey sheep, improved management practices often yield greater benefits than genetic interventions, due to the low repeatability of reproductive traits and the influence of flock structure and ewe parity[26]. Similarly, in Rahmani ewes, managing nutrient intake during late pregnancy-particularly in multiparous individuals-helps control weight loss and promotes better lamb birth weight and postnatal growth. High-protein diets further support lamb development[27]. Maternal body condition is essential for both reproductive efficiency and feed utilization, with direct implications for flock productivity[28]. Lamb weight also correlates strongly with dam weight, especially at weaning, underscoring the complex interaction of maternal and environmental influences on lamb growth[29].

In Indigenous and crossbred sheep, live weight and body measurements serve as key growth indicators, with breed, sex, and birth type significantly influencing performance[30]. Ewe age also affects lamb weight outcomes[31], while nutritional improvements, particularly for first-lambing ewes, contribute to enhanced growth trajectories[32]. Maintaining optimal environmental conditions remains essential for realizing the full growth potential of lambs and improving overall system productivity.

Further studies underscore these findings. Vlahek[33] identified birth type, sex, and birth number as key influences on Romanov lamb birth weight. Lupi[34] emphasized the role of flock management and twinning in growth. Nirban[35] and Singh[36] reported that sex, parity, and ewe weight significantly affect body weight and pre-weaning traits. Vatankhah and Salehi[37] demonstrated that selecting for mating weight can improve growth in Lori Bakhtiari sheep, while Assan and Makusa[38] confirmed that single-born and male lambs consistently achieve higher birth weights. Collectively, these studies highlight the importance of targeted growth strategies for improving overall flock performance.

Type 3 ANOVA (Model 2) revealed that rams significantly influence lamb weight at all stages of growth, emphasizing their crucial role in breeding decisions. Environmental factors also play a significant role in determining lamb weight.

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As shown in Table 3, rams contribute significantly to the variance in lamb weight, with their impact increasing as lambs age. The moderate heritability observed, particularly at six months and one year, underscores the importance of selecting rams with desirable traits for breeding to enhance lamb growth.

Variance component	The weights (Kg)			
	Birth	**Weaning**	**6 months**	**Annual**
Vs	0.02326	0.694	18.9368	38.8642
Vw	0.53	14.55	40.96	85.48
h^2 ± SE	0.17±0.08	0.18±0.07	0.32±0.04	0.31±.05

Table 3. Variance component and heritability ± standard error for birth weight, weaning weight, weight at 6 months of age, and annual weight in Awassi rams (Models 2, 3).

Vs= Variance component of ram, Vw= Variance component of individual within ram, h^2= heritability. Mean of progeny for each ram= 20.34

Rams play a vital role in enhancing lamb weight, with their genetic influence driving growth at all stages. As lambs mature, their genetic potential becomes more evident. Selecting rams with desirable traits in breeding programs can significantly boost flock productivity and profitability. In Awassi sheep, both genetic and environmental factors contribute to weight variation, with heritability for weight increasing as lambs age, highlighting the growing importance of genetics. Rams are a key factor in weight variation, making them an ideal focus for selective breeding programs aimed at improving weight-related traits and overall outcomes in this breed (Table 3).

Research supports the significant influence of rams on birth and weaning weights in hairy ewes[39]. Nirban[35] and Singh[36] also emphasize the ram's pivotal role in shaping body weight and pre-weaning traits. Crossbreeding, such as between Awassi rams and Barki ewes, results in improved crossbred lamb weight and earlier puberty at higher weights[40]. To optimize lamb growth, genetic improvements are essential[24][41]. Breeding programs focused on genetic merit, combined with effective management and selection strategies, can further enhance sheep productivity[42]. By selecting sheep with superior genetic traits, breeders can achieve substantial gains in growth and weight improvement.

Mean breeding values decrease with age, suggesting that environmental factors play an increasingly important role in weight traits as lambs mature. Strong positive genetic correlations between weight traits are observed (Table 4), indicating that improving one trait can lead to improvements in others. Index selection, which considers multiple traits simultaneously, can be an effective strategy for enhancing overall flock performance.

Breeding values	BVBW	BVWW	BVW6M	BVYW	TBV
BV(S)	0.02±0.01	-0.11±0.01	-0.26±0.17	-0.53±0.15	-0.97±0.51
BVBW		0.96**	0.97**	0.96**	0.64**
BVWW			0.92**	0.98**	0.62**
BVW6M				0.93**	0.63**

Table 4. Average of breeding values of weights based on rams; and spearman correlation coefficients of breeding values for traits studies (birth, weaning, 6 months, and annual weights), N=110, Prob. > |r| under H0: Rho=0 (Model 4).

BV= breeding values; BVBW, BVWW, BVW6M, and BVYW= breeding values for birth, weaning, 6-month, and annual weight, respectively; TBV = total of. Mean of progeny for each ram= 20.34

Strong correlations between breeding values for different weight traits in Awassi sheep rams suggest that simultaneous improvement in multiple traits is possible through selective breeding. However, the decline in average breeding values, particularly for annual weight (Table 4), highlights the need to focus on enhancing growth at later stages to optimize overall weight gain. While the strong correlations indicate potential for efficient genetic improvement through single-trait selection, a more nuanced approach is necessary. Prioritizing birth weight alone could compromise annual weight gain. A balanced selection strategy that considers multiple traits is likely to yield the most favorable outcomes.

Table 5 shows strong positive correlations between breeding values and mean weights in Awassi sheep, indicating that higher total breeding values (TBV) are associated with greater weight. Selecting for breeding values effectively enhances weight-related traits.

	BV(S)				
The weights (Kg)	**BVBW**	**BVWW**	**BVW6M**	**BVYW**	**TBV**
MBW	0.96**				0.97**
MWW		0.97**			0.98**
MW6M			0.99**		0.99**
MYW				0.95**	0.97**

Table 5. Spearman correlation coefficients among breeding and phenotypic values (weights) of Awassi Sheep, N = 111, Prob > |r| under H0: Rho=0

BVBW, BVWW, BVW6M and BVYW = Breeding values of birth, weaning, 6 months and annual weights, respectively. TBV= Total breeding values. MBW, MWW, MW6M and MYW= Means of birth, weaning, 6 months and annual weights, respectively. Mean of progeny for each ram= 20.34

Breeding values (BVs) in Awassi sheep show a strong correlation with actual weights, confirming their reliability as predictors of genetic weight traits. The positive relationship between total breeding value (TBV) and mean weights (Table 5) highlights the strategic importance of BVs in selection programs focused on improving genetic merit. This high correlation between BVs and realized weights demonstrates their effectiveness in identifying genetically superior animals. Additionally, the clear link between TBV and improved average weights emphasizes the direct impact of BV-based selection on productivity. Thus, utilizing BVs for selection is a crucial strategy for driving consistent genetic progress and enhancing the economic performance of Awassi sheep flocks.

Table 6 illustrates the genetic performance of ram progeny. High breeding values (BVs) are effective in identifying rams that contribute to improved growth. Selecting rams with high total breeding values

(TBV) helps enhance the overall genetics of the flock. Rams with positive BVs and high mean weights are valuable for breeding, while those with negative BVs may be excluded from selection.

	Rams rank						
The wieghts (Kg)	**1st**	**2nd**	**3rd**	**and so on**	**109th**	**110th**	**111th**
MBW	5.22	5.34	5.14	…	3.83	3.91	2.00
BVBW	0.52	0.50	0.49	…	−0.48	−0.56	−0.64
MWW	20.99	20.83	20.39	…	15.50	15.39	15.52
BVWW	2.29	2.21	1.99	…	-2.06	-2.30	-2.34
MW6M	43.19	42.89	42.93	…	27.70	15.50	26.24
BVW6M	6.32	6.15	5.83	…	-7.15	−8.00	−8.52
MYW	71.68	71.60	71.90	…	43.78	43.89	40.54
BVYW	10.97	10.78	10.52	…	-11.33	-11.70	-13.48
TBV	20.11	19.63	18.83	…	-21.02	-22.56	-24.98

Table 6:.Ranking of Awassi rams by genetic merit and performance.

MBW, MWW, MW6M and MYW= Means of birth, weaning, 6 months and annual weights, respectively. BVBW, BVWW, BVW6M and BVYW= Breeding values of birth, weaning, 6 months and annual weights, respectively; TBV= Total breeding values. Mean of progeny for each ram= 20.34

Utilizing breeding values (BVs) for key weight traits allows for the precise identification of superior breeding rams. Strategically selecting rams with high total BVs is essential for maximizing the genetic potential of the flock, leading to enhanced productivity and profitability. The consistent genetic gains achieved through BV-based selection are illustrated in Table 6, which emphasizes the importance of genetic performance data in optimizing ram progeny growth. Therefore, prioritizing rams with higher total BVs is crucial for improving flock genetic merit, and deliberate selection based on BVs is vital for sustaining genetic progress.

Studies have shown that Menz sheep exhibit considerable genetic variability, which facilitates selective breeding improvements and earlier ram selection due to strong trait correlations[43]. Gizaw[44] suggests a two-stage process: first, selecting breeding values at a nucleus center, followed by farmer selection, which aligns with their preferences and accelerates genetic progress. Sustainable breeding programs must consider both farmer needs and environmental factors[45]. Meat sheep also show sufficient genetic variation for improvement[46]. Furthermore, genomic selection combined with inbreeding management can enhance genetic gain in Egyptian sheep[47]. Kumar et al.[48] identified AA and AB genotypes of the GH gene in Harnali sheep, with the AB genotype showing a positive trend for higher body weights at various growth stages.

Future research offers great potential to uncover the complex effects of nutrition, climate, and gene-environment interactions on sheep productivity. Exploring these interactions, alongside selective breeding to enhance genetic diversity, will lead to significant advancements in the sheep industry. By implementing optimized management practices, such as environmental control and proactive healthcare, rearing stress can be minimized, flock health improved, and overall productivity and profitability boosted. These efforts will contribute to a more sustainable future for sheep farming, particularly in arid regions.

4. Conclusions

This study highlights the significant effects of birth type, lamb sex, ewe parity, and ewe age on lamb weights. Strong correlations between traits support the reliability of early weight measurements as predictors of future growth, while moderate heritability underscores the important role of rams in breeding programs. To maximize genetic gains, a multi-trait selection strategy is essential, with an index approach that integrates both genetics and environmental factors being key to sustainable lamb production. These findings offer valuable insights for sheep farmers and breeders, enabling them to enhance lamb growth and productivity through informed genetic and environmental management.

Statements and Declarations

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Conflicts of Interest

The authors confirm that they have no conflicts of interest to disclose.

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Institutional Review Board Statement

This research adhered to the ethical principles of the Declaration of Helsinki and received approval from the Institutional Review Board of the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) (Protocol Code: z2/12/25, Approval Date: December 30, 2023).

References

1. ^*Al-Barakeh, F., Khashroum, A.O., Tarawneh, R.A., Al-Lataifeh, F.A., Al-Yacoub, A.N., Dayoub M, Al-Najjar, K. (2024). Sustainable Sheep and Goat Farming in Arid Regions of Jordan. Ruminants, 4(2):241-255. https://doi.org/10.3390/ruminants4020017*
2. ^*Kassem, R., W. Al-Azzawi, Khaled Al-Najjar, Y. Masri, S. Salhab, Z. Abdo, I. El-Herek, H. Omed, and M. Saatc i. (2010). Factors influencing the milk production of Awassi sheep in a flock with the selected lines at the Agr icultural Scientific Research Centre. Kafkas Univ. Vet Fak Derg., 16(3): 425-430. https://vetdergikafkas.org/ uploads/pdf/pdf_KVFD_667.pdf*
3. ^*Al-Momani, Ahmad, Mysa Ata and Khaled Al-Najjar. (2020). Evaluation of Weight and Growth Rates of A wassi Sheep Lambs. Asian Journal of Research in Animal and Veterinary Sciences, 5(3): 26-32. https://www.j ournalajravs.com/ index.php/ AJRAVS/article/view/114/227*
4. ^*Al-Najjar, K., A.Q. Al-Momani, A.N. Al-Yacoub, A. Elnahas, Reda Elsaid. (2022). Estimation of Genetic Para meters and Non-Genetic Factors for Milk Yield and Litter Size at Birth of Awassi Sheep in Drylands, Vol. 17, No. 2, P: 19-26. https://ejsgs.journals.ekb.eg/article_266898.html*
5. ^*Al-Najjar, Khaled, Al-Momani, A., Al-Yacoub, A., and Elsaid, R. (2021). Evaluation of Some Productive Char acteristics of Jordanian Awassi. International Journal of Livestock Research, 11(4), 1-6. https://ijlr.org/ ojs_jou rnal/ index.php/ ijlr/ article/view/480/260*

6. ^Nel, C.L., J, J.H., Rauw, W.M., & Cloete, S.W. (2023). Challenges and strategies for genetic selection of sheep better adapted to harsh environments. Animal Frontiers, 13(5), 43-52. https://doi.org/10.1093/af/vfad055
7. ^Lv, H., Agha, S., Kantanen, J., Colli, L., Stucki, S., Kijas, J.W., Joost, S., Li, H., & Marsan, P.A. (2014). Adaptations to Climate-Mediated Selective Pressures in Sheep. Molecular Biology and Evolution, 31(12), 3324. https://doi.org/10.1093/molbev/msu264
8. ^Al-Karablieh, E.K., & Jabarin, A.S. (2010). Different rangeland management systems to reduce livestock feeding costs in arid and semi-arid areas in Jordan. Quarterly Journal of International Agriculture, 49(2), 91-109. https://ageconsearch. umn.edu/record/155543/?v=pdf
9. ^Alkass, J.E., Hermiz, H.N. and Baper, M.I. (2021). Some aspects of reproductive efficiency in Awassi ewes: A review. Iraqi Journal of Agricultural Sciences, 52(1):20-27.
10. ^Gootwine, E., Zenu, A., Bor, A., Yossafi, S., Rosov, A. andPollott, G.E. (2001). Genetic and economic analysis of introgression of the B allele of the FecB (Booroola) gene into the Awassi and Assaf dairy breeds. Livest. Prod. Sci., 71(1): 49-58, http://dx.doi.org/10.1016/ S0301-6226(01)00240-8
11. ^Galal, S., Gürsoy, O., and Shaat, I. (2008). Awassi sheep as a genetic resource and efforts for their genetic improvement—A review. Small Ruminant Research, 79 (2-3), 99-108. https://doi.org/10.1016/j.smallrumres.2008.07.018
12. ^Al-Najjar, K.; Yasin, A. O. A.; Alshdaifat, M. M.; Dayoub, M.; Raheem, D. (2024a). Enhancing Lamb Weight Increase through Genetic and Environmental Strategies in Arid Environments. Preprints, 2024110256. https://doi.org/ 10.20944/ preprints202411.0256.v1
13. ^Al-Najjar, K.; Al yasin, A. O.; Alshdaifat, M. M.; Dayoub, M.; Raheem, D. (2024b). Factors Affecting Awassi Sheep Weight and Breeding Strategies in Arid Environments. Preprints, 2024100211. https://doi.org/10.20944/preprints 202410.0211.v1
14. ^Epstein, H. (1985). The Awassi sheep with special reference to the improved dairy type. FAO Animal Production and Health Paper, No. 57, pp. 282. https://www.cabidigitallibrary.org/doi/full/10.5555/19870537949
15. ^Weather Spark. (2024). Weather in Ma'an city in Jordan. Available online: https://weatherspark.com/y/98741/Average-Weather-in-Ma'an-Jordan-Year-Round#Sections-Temperature. (Accessed on 11 November 2024).
16. ^SAS, (2012). Institute Inc.: SAS/STAT User's Guide: Version 9.1, SAS Institute Inc., and Cary, NC, USA. https://www.sas.com/en_us/software/stat.html
17. ^Duncan, D.B. (1955). Multiple range and multiple F tests: Biometrics, 11, 1-42. http://176.9.41.242/doc/statistics/1955-duncan.pdf

18. ^Becker WA. (1992). A Fortran Program for testing and analyzing multiple comparisons. Journal of Educational Statistics, 17(4):344-353.

19. ^Hardjosubroto P. (1994). Breeding value of sires based on offspring weaning weight as a recommendation for selecting kebumen ongole grade cattle. Journal of Animal Science, 72(12):3456-3463.

20. ^Chedid Mabelle, JaberLina S., Giger-Reverdin Sylvie, Duvaux-Ponter Christine, and Hamadeh Shadi K. (2014). Review: Water stress in sheep raised under arid conditions. Canadian Journal of Animal Science. 94(2): 243-257. https://doi.org/10.4141/cjas2013-188

21. ^Sejian, V., Hyder I., V.P. Maurya, M. Bagath, G. Krishnan, Joy Aleena, P.R. Archana, Angela M. Lees, Davendra Kumar, Raghavendra Bhatta & S.M.K. Naqvi. (2017). Adaptive Mechanisms of Sheep to Climate Change. In: Sejian, V., Bhatta, R., Gaughan, J., Malik, P., Naqvi, S., Lal, R. (eds) Sheep Production Adapting to Climate Change. Springer, Singapore. https://doi.org/10.1007/978-981-10-4714-5_5

22. ^Gbangboche, A., Adamou-Ndiaye, M., Youssao, A., Farnir, F., Detilleux, J., Abiola, F., & Leroy, P. (2006). Non-genetic factors affecting the reproduction performance, lamb growth, and productivity indices of Djallonke sheep. Small Ruminant Research, 64(1-2), 133-142. https://doi.org/10.1016/ j.smallrumres. 2005.04.006

23. ^Mahala, S., Saini, S., Kumar, A., Prince, L., & Gowane, G. (2019). Effect of non-genetic factors on growth traits of Avikalin sheep. Small Ruminant Research, 174, 47-52. https://doi.org/10.1016/j.smallrumres.2019.03.006

24. a, bHagan, B.A., Salifu, S., Asumah, C., Yeboah, E.D., & Boa-Amponsem, K. (2022). Effects of genetic and non-genetic factors on body weight, pre-weaning growth, birth type and pre-weaning survivability of lambs in a sheep nucleus station. Department of Animal Production and Health, 34(4). lrrd34/4/3430bern.html

25. ^Petrovic, M.P., Muslic, D.R., Petrovic, V.C., & Maksimovic, N. (2011). Influence of environmental factors on birth weight variability of indigenous Serbian breeds of sheep. African journal of Biotechnology, 10(22), 4673-4676. https://www.ajol.info/ index.php/ ajb/article/view/94136

26. ^Magaña-Monforte, J.G., Huchin-Cab, M., Ake-López, R.J. et al. (2013). A field study of reproductive performance and productivity of Pelibuey ewes in Southeastern Mexico. Trop Anim Health Prod 45, 1771–1776 (2013). https://doi.org/10.1007/s11250-013-0431-2

27. ^Abd-Allah, M. (2013). Effects of parity and nutrition plane during late pregnancy on metabolic responses, colostrum production and lamb output of Rahmani ewes. Egyptian Journal of Animal Production, 50(3), 132-142.

28. ^Luis, J., Victoria, M., Feyjoo, P., Cáceres, E., Hernández, F., Vicente, J., & Astiz, S. (2019). Influence of Maternal Factors (Weight, Body Condition, Parity, and Pregnancy Rank) on Plasma Metabolites of Dairy Ewes and Their Lambs. Animals, 9(4), 122. https://doi.org/10.3390/ani9040122

29. ^Caro-Petrović, V., Petrović, M. P., Ružić-Muslić, D., Maksimović, N., Sycheva, I. N., Cekić, B., & Ćosić, I. (2020). Interrelation between body weights of sire, dam and their lambs at early stage of growth. Biotechnology in Animal Husbandry, 36(2), 205-214. https://doiserbia.nb.rs/Article.aspx?id=1450-91562002205C
30. ^Kader Esen, V., & Elmacı, C. (2021). The Estimation of Live Weight from Body Measurements in Different Meat-Type Lambs. Journal of Agricultural Sciences, 27(4), 469-475. https://doi.org/10.15832/ankutbd.719037
31. ^Walkom, S.F., & Brown, D.J. (2016). Genetic evaluation of adult ewe bodyweight and condition: relationship with lamb growth, reproduction, carcass and wool production. Animal Production Science, 57(1), 20-32.
32. ^Aktaş, A. H., Dursun, Ş., Doğan, Ş., Kiyma, Z., Demirci, U., and Halıcı, İ. (2015). Effects of ewe live weight and age on reproductive performance, lamb growth, and survival in Central Anatolian Merino sheep, Arch. Anim. Breed., 58, 451–459, https://aab.copernicus.org/articles/58/451/2015/aab-58-451-2015. pdf
33. ^Vlahek, I., A. Ekert kabalin, S. Menčik, M. Maurić maljković, A. Piplica, H. Kabalin, J. Šavorić, V. Sušić. (2021). The effect of non-genetic factors on the birth weight of Romanov sheep. Vet. arhiv, 91. 615-624,
34. ^Lupi, T.M., Nogales, S., León, J. M., Barba, C., & Delgado, J.V. (2015). Analysis of the Non-Genetic Factors Affecting the Growth of Segureño Sheep. Italian Journal of Animal Science, 14(1). https://doi.org/ 10.4081/ijas.2015.3683
35. a, bNirban L.K., Joshi R.K., Narula H.K., Singh H., Bhakar S. (2015). Genetic and non-genetic factors affecting body weights in Marwari sheep. Indian Journal of Small Ruminants, 21(1). 106-108. https://doi.org/10.5958/0973-9718.2015. 00029.X
36. a, bSingh H., Pannu U., Narula H.K., Chopra A., Murdia C.K. (2013). Influence of genetic and non-genetic factors on pre-weaning growth in Marwari sheep. Indian Journal of Small Ruminants, Volume 19, Issue 2: 142-145.
37. ^Vatankhah, M., & Salehi, S. (2010). Genetic and non-genetic factors affecting Lori-Bakhtiari ewe body weight and its relationship with productivity. Small Ruminant Research, 94(1-3), 98-102. https://doi.org/10.1016/j. small rumres. 2010.07.006
38. ^Assan N., S. M. Makuza. (2005). The Effect of Non-genetic Factors on Birth Weight and Weaning Weight in Three Sheep Breeds of Zimbabwe. Asian-Australasian Journal of Animal Sciences, 18(2): 151-157. https://doi.org/ 10.5713/ ajas.2005.151
39. ^Sánchez-Dávila, F., Bernal-Barragán, H., Padilla-Rivas, G. et al. (2015). Environmental factors and ram influence litter size, birth, and weaning weight in Saint Croix hair sheep under semi-arid conditions in Mexico. Trop Anim Health Prod., 47, 825–831. https://doi.org/10.1007/s11250-015-0795-6

40. ^*Eissa, M.M; El-wakeel, EL.A; Ahmed, M.H; Zahran, S.M and EL-Rewany, A.M. (2013). Effect of breed of ram on reproductive performance of Barki ewes and their lambs. Alexandria Science Exchange Journal, 34 (April-June), 222-227. https://journals.ekb.eg/article_3041_607f55a38b44d551da923d70fad00e79.pdf*
41. ^*Granleese, T., Clark, S.A., Swan, A.A. et al. (2015). Increased genetic gains in sheep, beef and dairy breeding programs from using female reproductive technologies combined with optimal contribution selection and genomic breeding values. Genet. Sel. Evol., 47, 70. https://doi.org/10.1186/s12711-015-0151-3*
42. ^*Kramarenko, A.S., Markowska, A.V., Salamatina, O.O., Kravchenko, O.O., & Kramarenko, S.S. (2021). Genetic and environmental factors influenced the birth and weaning weight of lambs. Ukrainian Journal of Ecology, 2021, 11(2), 195-201, birth-and-weaning-weight-of-lambs*
43. ^*Gizaw, S., Lemma, S., Komen, H., & Van Arendonk, J.A. (2007). Estimates of genetic parameters and genetic trends for live weight and fleece traits in Menz sheep. Small Ruminant Research, 70(2-3), 145-153. https://doi.org/10.1016/ j.smallrumres.2006.02.007*
44. ^*Gizaw S, Getachew T, Tibbo M, Haile A, Dessie T. (2015). Congruence between selection on breeding values and farmers' selection criteria in sheep breeding under conventional nucleus breeding schemes, animal, 5 (7): 995 - 1001. https://doi.org/ 10.1017/S1751731111000024*
45. ^*Gizaw, S., Komen, H., & Van Arendonk, J. A. (2010). Participatory definition of breeding objectives and selection indexes for sheep breeding in traditional systems. Livestock Science, 128(1-3), 67-74, https://doi.org/10.1016/ j.livsci.v2009.10.016*
46. ^*Sánchez-Molano, E., Kapsona, V.V., Oikonomou, S. et al. (2020). Breeding strategies for animal resilience to weather variation in meat sheep. BMC Genet, 2020. 21, 116, https://doi.org/10.1186/s12863-020-00924-5*
47. ^*El-Wakil, S.I. and Elsayed, M. (2013). Genetic, phenotypic and environmental trends towards improving body weight in Barki sheep. Egyptian Journal of Sheep and Goats Sciences, 8(2), 1-10. https://journals.ekb.eg/article_26769_ d92ae6e0a45a44fecc73b3aa1ce12cfc.pdf*
48. ^*Kumar, S., Yadav, A.S., Magotra, A. et al. (2024). Polymorphism of growth hormone (GH) gene and its association with performance and body conformation of Harnali sheep. Trop. Anim. Health Prod. 56, 116, https://doi.org/ 10.1007/s11250-024-03968-2*

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