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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-suited to arid climates, demonstrating the adaptability of sheep farming to diverse environments. However, productivity challenges require selective breeding and improved management. This study, conducted at Al-Fjaj Station, Jordan, analyzed 2,263 Awassi sheep weight records from a semi-intensive system to evaluate the environmental and genetic factors affecting lamb weight, and to estimate heritability and breeding values.

Variance analysis showed that birth type, sex, parity, and age of ewe at lambing significantly influenced lamb weight at all studied stages. Single-born lambs were heavier at birth, males outweighed females, and younger ewes produced lighter lambs with compensatory growth. Strong positive correlations existed between weaning, six-month, and yearling weights, while birth weight had a weaker impact on later weight.

Analysis of Variance showed rams had the greatest influence on lamb weights, while heritability contributed moderately. Strong genetic correlations suggest selection for one trait can improve others. Mean breeding values declined with age due to environmental factors, supporting index selection for trait enhancement. Strong correlations between breeding values and weights indicate selecting high-value individuals can boost genetic potential and predict performance.

Selecting rams with superior breeding values is crucial for improving weight gain in future generations. Mean weights serve as key indicators for genetic improvement and economic viability. This study highlights birth type, sex, parity, and age of ewe as key factors in lamb growth,

emphasizing the advantages of single lambs and males. An index selection approach integrating genetics and environment is recommended for sustainable lamb production in arid regions.

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1. Introduction

Ovine agriculture displays broad adaptability across varied environments and economies. Arid regions, however, present unique disease challenges for sheep and goats, influenced by seasonal rainfall[1]. The Awassi breed, known for its fat tail and Middle Eastern origins, excels in these conditions. Traditionally managed in semi-intensive systems, its adaptability allows a successful introduction to diverse global locations.

Boosting Awassi sheep productivity in the Middle East necessitates a multifaceted approach. Key strategies include: early identification of high-yielding ewes, selection for lamb growth[2], targeted nutrition for peak-age ewes[3], strategic ram selection[4], optimized prenatal nutrition, and meticulous neonatal care[5]. These integrated measures enhance flock performance.

Although Awassi sheep are well-suited to arid environments, their low prolificacy and significant environmental and socioeconomic constraints in Jordan[6] hinder their productivity. Selective breeding efforts have achieved some success in increasing weight and milk production[7][8][9], but further improvements require a comprehensive approach. This includes implementing enhanced management strategies and targeted genetic selection, recognizing that lamb weight is influenced by birth type, sex, ewe parity, and age. Early weight measurements are valuable for predicting future growth, and the moderate heritability of traits highlights the importance of ram selection[10]. Optimizing lambing practices and adjusting breeding strategies to address both genetic and environmental factors are critical for improving Awassi sheep growth rates[11].

Al-Fjaj Station maintains two Awassi sheep types: the hardy local breed and the selectively bred, high-milk-producing improved variant[12].

This study investigates factors affecting Awassi sheep's weight at key growth stages, analyzing environmental and genetic influences. It aims to assess genetic improvement potential by estimating heritability and breeding values and to rank rams for optimized breeding strategies.

2. Materials and Methods

2.1. Location

This study occurred in 2023 at Al-Fjaj Station, Ma'an Governorate, Jordan, where Awassi sheep are managed semi-intensively. The station, 200 km south of Amman, provides a suitable environment for studying weight influences (Figure 1). Ma'an experiences hot summers (May-September, highs >29°C) and cool winters (November-March, highs <17°C)[13].

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

2.2. The sheep herd

Sheep were managed semi-intensively, grazing daily despite dry-season pasture decline. During June/July mating, selected rams naturally bred with 25 ewes, averaging 20 lambs/year. Pregnant ewes were penned for lambing and nursed lambs for three days. Most births occurred in October/November. The twinning rate was 20%, primarily in non-previous-year lambing ewes. Lambs were weighed, tagged, and recorded with sex, birth type, date, ID, and weight within 24 hours.

Lambs nursed freely for 15 days, then underwent controlled suckling until 2 months weaning. Weights were recorded at weaning, 6 months, and 1 year. Mature ewes grazed with supplemental feed (250-500g, 0.5-1kg in winter). Lambs were weighed at birth, weaning, 6 months, and annually. Pregnant ewes received 0.5kg alfalfa hay and 1.5-1.8kg concentrate. Weaning was 2 months, with weak lambs suckling until 14kg. Lambs had free access to starter pellets and alfalfa hay.

doi.org/10.32388/14ZVQT

Ewes received forage legumes/cereals in dry periods, crop residues/shrubs otherwise, and concentrates/hay/straw in winter. Pregnant ewes received a specialized concentrate mix. Lamb weights were tracked at birth, weaning, 6 months, and annually. Lambs and ewes followed a controlled lactation and supplementary feed program.

2.3. Data analyses

The 2015-2023 dataset included 2,262 Awassi sheep weight records (111 rams, 1,714 ewes, 1,908 lambs). Incomplete lamb records were excluded. SAS GLM[14] was used for statistical analysis, applying a fixed 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 ijklth 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 ijklth observations on the ewe's age at lambing. X_{ijkl}= the kth 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[15] was used to notice differences between means.

Partial correlation coefficients were calculated from the SSCP errors matrix (Prob.>|r|). Variance components were estimated using the paternal half-sib method[16]. A mixed model was then applied.

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

Where, $Y_{ijkl} =$ Birth weight, weaning weight, weight at 6 months, and annual weight of ijklth 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:

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

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[17].

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

Variance analysis (Model 1) showed birth type, lamb sex, parity, and ewe age significantly influenced lamb weight traits. Birth type and parity consistently affected all weight stages, while lamb sex influenced birth, weaning, and annual weights. Ewe age notably affected weaning and 6-month weights, highlighting maternal influence.

Table (1) shows single lambs outweigh twins, and males outweigh females. Younger ewes produce lighter birth-weight lambs, but they catch up. Higher parity ewes have heavier birth weight lambs, but lighter weaning weights. Weaning and 6-month weights show the most variation. Ewe age positively influences lamb weight, especially at weaning and 6 months.

doi.org/10.32388/14ZVQT

Factors		Birth weights	Weaning weights	weights at 6 months	Annual weights
Overall mean (2262)		4.41±0.02	18.03±0.08	35.59±0.16	62.59±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 (1125)	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 (38)	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%.

Table (2) shows positive correlations between lamb weights at different ages, with strong correlations between weaning, 6-month, and yearling weights. Birth weight has less influence on later weights.

doi.org/10.32388/14ZVQT

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.*

Type 3 ANOVA (Model 2) showed rams significantly influence lamb weight at all ages, highlighting their importance in breeding. Environmental factors also affect lamb weight.

Table (3) shows rams significantly impact lamb weight variance, which increases with age. Moderate heritability, especially at 6 months and 1 year, highlights the importance of ram selection for breeding.

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
$h^2 \pm SE$	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

doi.org/10.32388/14ZVQT

Mean breeding values decrease with age, indicating increased environmental influence. Strong positive genetic correlations exist between weight traits (Table 4). Index selection can improve multiple traits simultaneously.

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

Table (5) shows strong positive correlations between breeding values and mean weights in Awassi sheep. High TBV correlates with high weights. Breeding value selection effectively enhances weight traits.

doi.org/10.32388/14ZVQT

The weights (Kg)	BV(S)				
	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

Table (6) shows ram progeny's genetic performance. High breeding values (BV) identify rams for improved growth. Selecting rams with high total breeding value (TBV) enhances flock genetics. Rams with positive BVs and high mean weights are valuable, while those with negative BVs may be excluded.

The wieghts (Kg)	Rams rank						
	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

4. Discussion

Lamb weight is affected by many factors, including type of lamb, sex of lamb, number of litters, and age of the ewes. Single lambs often grow faster than twins due to easier access to milk from their mothers, resulting in higher weaning weights. Male lambs grow faster than females due to testosterone, resulting in higher birth, weaning, and annual weights. Older ewes generally provide better growth conditions for lambs than younger ewes, resulting in higher weights at all stages of growth. These factors collectively affect lamb weight at birth, weaning, and throughout their lives until maturity weight (Table 1).

Resource limitations in arid environments specifically forage and water scarcity restrict growth in lambs and adult females. Survival and reproduction may be prioritized over maximal weight gain through early maturity and specialized feeding[18]. Native strains, which are genetically adapted to these conditions, often show slower growth but have greater resilience[19].

Early lamb weight is crucial as it strongly predicts future growth, particularly at weaning, six months, and one year. Lambs that are heavier at these stages typically maintain their advantage, leading to more efficient growth and higher weight production. While birth weight has some influence, later weights are more reliable for predicting growth potential, enabling better management and breeding decisions that enhance overall flock performance. This understanding aids in selecting and nurturing lambs with the best prospects, ultimately improving productivity and profitability in sheep farming (Table 2).

Extensive research has shown that various non-genetic factors play a critical role in sheep productivity. For instance, the age at first lambing significantly affects the performance of Djallonke sheep[20], while Avikalin sheep experience rapid early growth followed by a slowdown, underscoring the importance of effective environmental management strategies[21]. Environmental conditions are key determinants of lamb birth and weaning weights, directly influencing early growth and necessitating management enhancements to optimize pre-weaning performance[22]. In high-yielding Serbian sheep, particularly maiden ewes carrying multiple lambs, targeted nutritional strategies are crucial for ensuring the birth of lambs with optimal weight[23].

In Pelibuey ewes, improved management practices provide greater benefits than genetic modifications due to the low repeatability of reproductive traits and the influence of flock structure and parity[24]. Likewise, Rahmani ewes in late pregnancy have higher nutrient requirements and controlled weight loss in multiparous ewes enhances lamb birth weight and growth, with high-protein diets further supporting lamb development[25]. Maternal body condition traits are crucial for both maternal efficiency and feed utilization, directly influencing overall flock productivity[26]. Additionally, lamb weight is strongly correlated with dam weight, particularly at weaning, highlighting the complex interplay of factors influencing lamb growth[27].

In Indigenous and crossbred sheep, live weight and body measurements are key indicators of growth performance, with breed, birth type, and sex also playing significant roles[28]. Ewe age notably affects lamb weight[29], while nutritional improvements, particularly for first-time ewes, enhance lamb growth trajectories[30]. Maintaining optimal environmental conditions is essential for maximizing growth potential and overall productivity in sheep farming systems.

Research has identified key factors affecting lamb and sheep growth. Vlahek[31] found birth type, sex, and birth number influence Romanov lamb birth weight. Lupi[32] highlighted the role of flock management and twin births in growth. Nirban[33] and Singh[34] noted that sex, parity, and ewe weight determine body weight and pre-weaning traits. Vatankhah and Salehi[35] showed that selecting for mating weight boosts Lori Bakhtiari sheep weight, while Assan and Makusa[36] found single and male lambs have higher birth weights. These studies emphasize the need for targeted growth strategies to improve flock performance.

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

Research indicates that rams significantly influence birth and weaning weights in hairy ewes[37]. Nirban[33] and Singh[34] further emphasize the ram's crucial role in body weight and pre-weaning traits. Crossbreeding, such as between Awassi rams and Barki ewes, improves crossbred lamb weight, leading to earlier puberty at higher weights[38]. To optimize lamb growth, genetic gains are essential[22][39], and breeding programs focused on genetic merit, coupled with effective management and selection, can enhance sheep productivity[40]. Selecting sheep with superior genetic traits yields additional benefits for growth and weight improvement.

Strong correlations between breeding values for different weight traits in Awassi sheep rams suggest a potential for simultaneous improvement through selective breeding. However, declining average breeding values, particularly for annual weight (Table 4), highlight the need to focus on improving later-stage growth to optimize overall weight gain. While strong correlations suggest a potential for efficient genetic improvement through single-trait selection, a more nuanced approach is necessary. Prioritizing birth weight alone may compromise annual weight gain. A balanced selection strategy, considering multiple traits, would likely yield the best outcomes.

Awassi sheep breeding values (BVs) exhibit a strong correlation with actual weights, validating their use as dependable predictors of genetic weight traits. The observed positive association between total breeding value (TBV) and mean weights (Table 5) reinforces the strategic importance of BVs in selection programs aimed at enhancing genetic merit. The high correlation between BVs and realized weights highlights their power in accurately pinpointing genetically superior animals. Moreover, the clear connection between TBV and improved average weights underscores the direct impact of BV-based selection on productivity. Therefore, leveraging BVs for selection is a critical strategy for driving consistent genetic progress and optimizing the economic performance of Awassi sheep flocks.

Utilizing breeding values (BVs) for key weight traits enables the precise identification of superior breeding rams. Strategically selecting rams with high Total-BVs is crucial for maximizing flock genetic potential, resulting in enhanced productivity and profitability. The consistent genetic gains achieved through BV-based selection are demonstrated in Table 6, which highlights the critical role of genetic performance data in optimizing ram progeny growth. Therefore, prioritizing rams with higher Total-BVs is essential for elevating flock genetic merit, and deliberate selection based on BVs is indispensable for sustained genetic progress.

Studies show Menz sheep have significant genetic variability, allowing for selective breeding improvements and earlier ram selection due to high trait correlations[41]. Gizaw[42] suggests a two-stage process: nucleus center breeding value selection, then farmer selection, aligning with preferences, and speeding progress. Sustainable breeding requires considering farmer needs and the environment[43]. Meat sheep also show sufficient genetic variation for improvement[44]. Genomic selection with inbreeding management enhances genetic gain in Egyptian sheep[45].

Future research holds immense promise for revealing the intricate impacts of nutrition, climate, and gene-environment interactions on sheep productivity. Investigating these interactions and leveraging selective breeding to enhance genetic diversity will drive significant advancements in the sheep industry. Implementing optimized management practices, including environmental control and proactive healthcare, will mitigate rearing stress, improve flock health, and ultimately enhance productivity and profitability, fostering a sustainable future for sheep farming in arid regions.

5. Conclusions

In conclusion, this study demonstrates the significant impact of birth type, lamb sex, ewe parity, and ewe age on lamb weights. Strong trait correlations validate early weight measurements as reliable growth predictors, while moderate heritability highlights the ram's crucial role in breeding programs. To maximize genetic gains, a multi-trait selection strategy is essential, with an index approach integrating genetics and environment being key to sustainable lamb production. These findings provide sheep farmers and breeders with valuable insights for enhancing lamb growth and productivity through informed genetic and environmental management.

Statements and Declarations

Acknowledgments

The authors sincerely appreciate the invaluable contributions of the University of Turku, the Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD), the University of Lapland, the National Center for Agricultural Research (NARC), and the General Commission for Scientific Agricultural Research (GCSAR). Their unwavering support was instrumental in the successful completion of this research.

Conflicts of Interest

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

Funding

This research was carried out without any external financial assistance.

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).

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Supplementary data: available at https://doi.org/10.32388/14ZVQT

Declarations

Funding: No specific funding was received for this work.

Potential competing interests: No potential competing interests to declare.