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Influence of biological and environmental factors on growth of Ouled Djellal lambs (*Ovis aries*) in Northeastern Algeria

Influencia de factores biológicos y ambientales en el crecimiento de corderos Ouled Djellal (*Ovis aries*) en el noreste de Argelia

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ABSTRACT

This study evaluated the influence of biological (sex, litter size) and environmental (region, year, and month of birth) factors growth performance of Ouled Djellal lambs raised under semi-intensive systems in northeastern Algeria. Data from 2,605 lambs born between 2015 and 2021 across three wilayas (administrative divisions equivalent to provinces) Constantine, Bordj Bou Arréridj, and Oum El Bouaghi were analyzed using generalized linear models. Body weights were recorded at birth, 30, 60, 90, and 120 days of age, and average daily gains for the corresponding periods (ADG_{0-90}, ADG_{90-120}, ADG_{0-120}) were calculated. Results showed that the mean BW, W90, and W120 were 4.48 ± 0.16 kg, 18.79 ± 0.10 kg, and 21.82 ± 0.14 kg, respectively. The mean ADG_{0-90}, ADG_{90-120}, and ADG_{0-120} were 159.6 ± 1.08, 107.2 ± 1.64, and 144.7 ± 1.18 g·day^{-1}, respectively. These results varied according to biological and environmental factors (P<0.05). Males were consistently heavier and grew faster than females (P<0.0001), single births outperformed twins throughout the growth period (P<0.0001). Lambs born in October and August showed the highest Body weights and W30 (P<0.0001, P<0.05) respectively. Year and farm location (wilaya) also had significantly affected growth lambs, with the best performances recorded in 2019 and in Bordj Bou Arréridj. Several key interactions among these factors highlighted the combined effect on lamb performance. These findings highlight the crucial role of non-genetic factors in determining lamb growth under semi-arid conditions. Aligning lambing periods with favourable environmental conditions and adapting management practices to regional contexts could considerably enhance productivity in Algeria's semi-intensive sheep systems.

Key words: Ouled Djellal lambs; growth performance; non-genetic factors; average daily gain; semi-intensive system

RESUMEN

Se realizó un estudio con el objeto de evaluar la influencia de factores biológicos (sexo y tamaño de camada) y ambientales (región, año y mes de nacimiento) sobre el rendimiento de crecimiento de corderos Ouled Djellal criados en sistemas semi-intensivos en el noreste de Argelia. Se analizaron datos de 2.605 corderos nacidos entre los años 2015 y 2021 en tres wilayas (divisiones administrativas equivalentes a provincias): Constantine, Bordj Bou Arréridj y Oum El Bouaghi, utilizando modelos lineales generalizados. Los pesos corporales se registraron al nacimiento y a los 30, 60, 90 y 120 días de edad , y se calcularon las ganancias medias diarias para los periodos correspondientes (GMD_{0-90}, GMD_{90-120} y GMD_{0-120}). Los resultados mostraron que los pesos medios al nacimiento, entre los 90 y 120 días fueron de 4,48 ± 0,16 kg, 18,79 ± 0,10 kg y 21,82 ± 0,14 kg, respectivamente. Las ganancias medias diarias GMD_{0-90}, GMD_{90-120} y GMD_{0-120} fueron de 159,6 ± 1,08; 107,2 ± 1,64 y 144,7 ± 1,18 g·día^{-1}, respectivamente. Estos resultados variaron según los factores biológicos y ambientales (P<0,05). Los machos fueron consistentemente más pesados y presentaron mayores tasas de crecimiento que las hembras (P<0,0001), mientras que, los corderos únicos superaron a los gemelos durante todo el periodo de crecimiento (P<0,0001). Los corderos nacidos en octubre y agosto presentaron los mayores pesos al nacimiento y a los 30 días (P<0,0001 y P<0,05, respectivamente). También se observaron efectos significativos del año y de la región, registrándose los mejores rendimientos en Bordj Bou Arréridj y en 2019. Además, varias interacciones significativas entre estos factores evidenciaron su influencia combinada sobre el rendimiento de los corderos. Estos resultados demuestran que los factores no genéticos desempeñan un papel importante en el crecimiento de los corderos bajo condiciones semiáridas. Ajustar los periodos de parición a condiciones ambientales favorables y adaptar las prácticas de manejo al contexto regional podría mejorar considerablemente la productividad de los sistemas ovinos semi-intensivos en Argelia.

Palabras clave: Corderos Ouled Djellal; rendimiento de crecimiento; factores no genéticos; ganancia media diaria; sistema semi-intensivo

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INTRODUCTION

Sheep (*Ovis aries*) production is a key component of Algeria's agricultural economy, contributing significantly to meat supply and supporting rural livelihoods across the country's diverse agroecological zones. According to the Ministry of Agriculture most recent official data (2019) [1], the national flock was estimated at around 29 million head, with the Ouled Djellal breed accounting for nearly 60% of the total. This breed is known for its adaptability, hardiness, and high meat potential, forms the basis of red meat production in Algeria. The extensive distribution, particularly in plateaus and semi-arid regions, demonstrates its remarkable capacity to thrive in arid climates [2].

Birth weight, weaning weight, and average daily gain (ADG) are key indicators used to evaluate productivity and management efficiency in sheep production systems. These quantitative traits are influenced by several non-genetic factors, including biological characteristics such as sex and litter size, environmental conditions related to region and time of birth (season and year), as well as maternal characteristics like ewe age, parity, body condition, and live weight. The independent or combined effects of these factors may mask the expression of genetic potential and complicate selection programs [3, 4, 5, 6].

Previous Algerian studies have evaluated the effects of these factors in Ouled Djellal and other local breeds [2, 7, 8, 9, 10]. Comparable effects of these factors have been reported in Morocco [11], Tunisia [12], Sudan [13], Ethiopia [3], Benin, [4], Pakistan [14], and Mexico [15]. In Algeria, most studies used limited datasets and few explanatory variables, which limits the analysis of interaction effects among factors [2, 7, 8, 9, 10].

To optimize management and increase productivity in semi-arid production systems, it's crucial to understand the interaction between biological and environmental factors that affect lamb growth. Therefore, this study aimed to evaluate the effects of sex, litter size, region, year, and month of birth on the growth performance of Ouled Djellal lambs raised under semi-intensive systems in northeastern Algeria, as well as to identify significant interactions among these factors.

MATERIALS AND METHODS

Study area and period

The study took place between 2015 and 2021 in three wilayas in northeastern Algeria: Constantine, Bordj Bou Arréridj, and Oum El Bouaghi, which are elevated at a height of 694, 928 and 902 meters above sea level respectively. These regions are characterized by a semi-arid climate with cold winters, hot summers, and an average annual temperature of approximately 15°C. Annual rainfall ranges between 300 and 500 mm, with most precipitation occurring between November and March. The soils are mainly clay-limestone, which supports cereal-pasture systems that are used for both grazing and fodder production [16].

Animals and management practices

The study involved 2,605 Ouled Djellal lambs, born between August and December. The animals were raised under semi-intensive systems that are typical of Algerian pilot farms. The feeding system relied primarily on grazing natural and cultivated pastures, with occasional summer supplementation consisting of cereal stubble, oat hay, straw, wheat bran, and commercial concentrates. When there was a lack of food or bad weather, the animals were housed and given stored forages and formulated rations.

Mating takes place mostly mainly in autumn, but year-round reproduction is feasible in Algeria, just as in many other Mediterranean countries. To synchronize lambing with optimal forage availability, spring mating (August to January, peaking between September and December) was usually selected. After birth, lambs suckled exclusively for about two months before being gradually introduced to solid foods like wheat bran and straw. Weaning occurred at about 90 days (d) of age.

Data collection and growth traits

Data were collected from birth to 120 d of age. Body weights were measured at birth (BW), 30, 60, 90, and 120 d of age (W30, W60, W90, W120). ADG were calculated for the following intervals: from birth to 90 d (ADG_{0-90}), from 90 to 120 d (ADG_{90-120}), and from birth to 120 d (ADG_{0-120}).

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics (version 25.0). Descriptive statistics were generated for all traits, and general linear models (GLM) were applied to evaluate the influence of non-genetic factors on lamb growth performance. The model included the most important biological and environmental effects that are relevant to semi-intensive systems and their interactions, as shown below:

$$W_{ijklmn} = \mu + S_i + L_j + Y_k + M_l + P_m + (S \times L)_{ij} + (S \times Y)_{ik} + (S \times M)_{il} + (M \times Y)_{lk} + (M \times L)_{lj} + (M \times L \times Y)_{ljk} + (M \times S \times Y)_{lik} + (L \times S \times Y)_{jik} + e_{ijklmn}$$

Where:

w_{ijklmn} = birth weight (BW), body weights (W), or average daily gain (ADG) of the n_{th} lamb of sex $_i$, of litter size $_j$, in year $_k$, of birth month $_l$, in farm location $_m$;

μ = general average;

S_i = fixed effect of the sex i (2 classes female and male);

L_j = fixed effect of the litter size j (2 classes: single and twin);

Y_k = fixed effect of the year k (7 years: from 2015 to 2021);

M_l = fixed effect of the birth month I (3 months: august, September and October);

P_m = fixed effect of the farm location m (3 locations: Constantine, Oum El Bouaghi, Bordj Bou Arréridj):

e_{ijklmn} = residual random effect.

The two-way interactions between the factors were studied, and only those which were significant have been kept in the final model.

For the three traits, the data distribution in the different classes of fixed effects is given in Table I. The portion of the variation due to the model is provided through the coefficient of determination (R^2).

RESULTS AND DISCUSSION

Growth performance

Mean birth weight (BW) was 4.48 ± 0.16 kg, increasing steadily to 21.82 ± 0.14 kg at 120 d (W120). The most rapid growth occurred during the early period of life, when lambs more than doubled their birth weight by 30 d. The highest ADG was recorded during the pre-weaning period (ADG_{0-90} = 159.6 ± 1.08 g·d^{-1}), followed by a marked decline during the post-weaning period 107.2 ± 1.64 g·d^{-1} (ADG_{90-120}). (FIGS. 1 and 2).

This decrease reflects the typical slowdown in growth associated with weaning stress and the transition from milk to solid feed. Overall, the growth performance observed in the present study exceeded that reported in most previous Algerian studies. Djellal *et al.* [2] reported higher birth weights (5.30 kg) in a sample of 30 lambs, while Mohammedi *et al.* [17] observed lower birth weights (3.3 – 3.9 kg) but comparable weights at 120 d weights (21.95 kg).

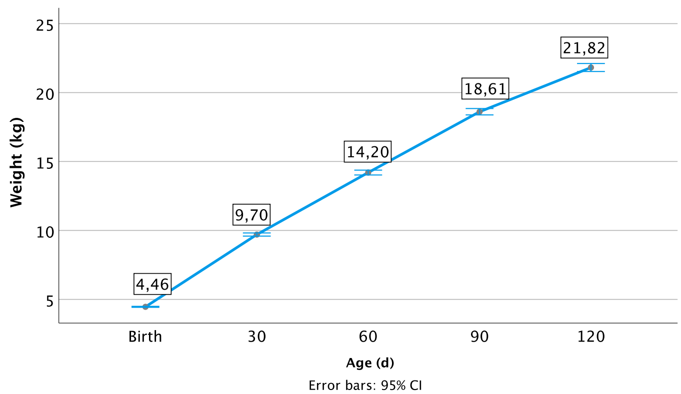

FIGURE 1. Body weight growth curve of Ouled Djellal lambs from birth to 120 days

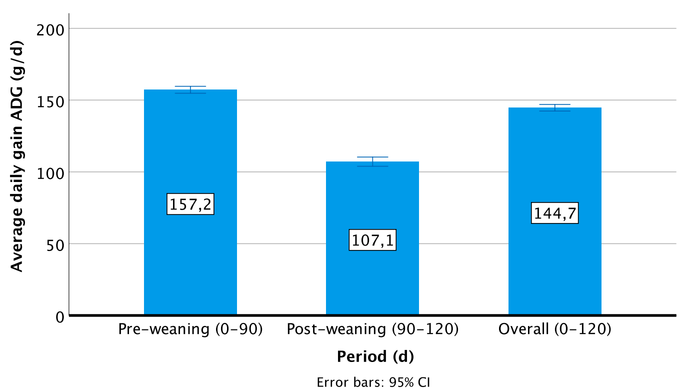

FIGURE 2. Average daily gain during the pre-weaning, post-weaning, and overall growth periods in Ouled Djellal lambs

Nevertheless, both studies reported comparable estimated pre-weaning gains (163.56 g·d^{-1}, 153.3 g·d^{-1}, respectively). Zidane *et al.* [10] and Bendiab & Dekhili. [8] recorded lower mean birth weights (3.04 – 3.8 kg), and 90–d weights (14.5 – 16.3 kg). In contrast, Boubekeur *et al.* [9] and Baa *et al.* [7] recorded higher performance in Rambi and D'man lambs (25 kg at 100 d, 211 g·d^{-1}; 23.8 kg at 120 d; 176 g·d^{-1}), while Yerou *et al.* [18] reported lower gains (132 – 141 g·d^{-1}) in Hamra lambs.

Such variability among studies may be explained by differences in feeding practices, ewe nutrition, genetic potential, and environmental conditions. The present study, which is based on a large dataset of 2,605 lambs, provides robust and representative estimates of Ouled Djellal growth performance under semi-intensive production systems in Algeria.

Main effects of biological and environmental factors

Effect of sex

Males and females accounted for 49.25% and 50.75% of the lamb population, respectively. Sex had a highly significant effect on all growth traits (P<0.0001). Males were consistently heavier, ranging from 4.57 ± 0.02 kg vs. 4.39 ± 0.02 kg at birth (a 4.1% difference) to 23.06 ± 0.22 kg vs. 20.47 ± 0.18 kg at 120 d (a 12.7% difference) (TABLE I).

They also grew faster, with ADG advantages of 11.6% (0–90 d), 17.2% (90–120 d), and 14.8% (0–120 d) (TABLE II).

These findings are consistent with previous Algerian studies [9, 10, 19], which attributed male superiority to testosterone activity, better feed conversion, faster muscle development, and stronger suckling behaviour. However, Djellal *et al.* [2] and Baa *et al.* [7] reported no significant pre-weaning differences between the sexes.

Consistent with the present results, several other studies have also observed a male advantage in lamb growth. These include studies conducted in Tunisia [20], on D'man lambs; in Morocco on Timahdite , Sardi, Boujaâd, Béni Guil and breeds [11, 21, 22, 23], in Pakistan on Kajli [14], in Benin on Djallonké [4], in India on Avikalin and Sonadi [13, 24], in Ethiopia on Washera [3], in Rajasthan on Bharat Merino sheep [6], in Zimbabwe on Sabi, Dorper and Merino sheep [25], on Icelandic sheep breed [5], and on West African Dwarf sheep [26].

Some authors have suggested that the effect of sex diminishes with age under uniform feeding conditions, whereas others have confirmed a persistent male advantage, depending on breed, management and environmental factors [27, 28, 29]. Overall, sex remains a key determinant of growth performance and should be considered in breeding strategies.

Effect of litter size

Regarding birth type, 64.6% of lambs were single-born while 35.4% were twins. Litter size had a highly significant effect on growth performance (P<0.0001): singletons were consistently heavier,

TABLE I
Body weights of Ouled Djellal lambs from birth to 120 days: Effects of biological and environmental factors

Trait		BW		W30		W60		W90		W120	
		N	LSM ± SE	N	LSM ± SE	N	LSM ± SE	N	LSM ± SE	N	LSM ± SE
Overall		2605	4.48 ± 0.16	2551	9.80 ± 0.50	2382	14.39 ± 0.77	2240	18.79 ± 0.10	1802	21.82 ± 0.14
Sex	Male	1283	4.57 ± 0.02[b]	1258	10.17 ± 0.73[b]	1206	14.91 ± 0.11[b]	1146	19.67 ± 0.15[b]	940	23.06 ± 0.22[b]
	Female	1322	4.39 ± 0.02[a]	1293	9.44 ± 0.66[a]	1176	13.85 ± 0.10[a]	1103	17.88 ± 0.13[a]	862	20.47 ± 0.18[a]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Litter size	Singleton	1684	4.67 ± 0.02[b]	1643	10.31 ± 0.06[b]	1507	15.12 ± 0.10[b]	1402	19.70 ± 0.13[b]	1112	22.81 ± 0.19[b]
	Twin	921	4.12 ± 0.02[a]	908	8.88 ± 0.08[a]	875	13.12 ± 0.11[a]	847	17.28 ± 0.15[a]	690	20.22 ± 0.21[a]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Birth month	August	468	4.34 ± 0.04[a]	466	10.04 ± 0.12[b]	463	14.29 ± 0.17[a]	450	18.63 ± 0.22[a]	426	21.92 ± 0.27[a]
	September	1537	4.43 ± 0.02[a]	1530	9.69 ± 0.61[a]	1449	14.46 ± 0.10[a]	1390	18.84 ± 0.14[a]	1112	21.87 ± 0.20[a]
	October	467	4.64 ± 0.04[b]	444	9.83 ± 0.12[ab]	418	14.20 ± 0.16[a]	392	18.66 ± 0.22[a]	251	21.17 ± 0.31[a]
	P value		***P*<0.0001**		***P*<0.05**		*P*>0.05		*P*>0.05		*P*>0.05
Year of birth	2017	342	4.38 ± 0.05[a]	328	8.49 ± 0.98[a]	328	11.78 ± 0.59[a]	328	16.92 ± 0.24[a]	328	18.76 ± 0.32[a]
	2018	406	4.38 ± 0.04[a]	386	9.90 ± 0.11[b]	343	15.41 ± 0.17[c]	266	19.28 ± 0.25[b]	–	–
	2019	437	4.62 ± 0.04[b]	427	11.20 ± 0.11[c]	359	17.84 ± 0.18[d]	344	23.79 ± 0.27[c]	312	28.88 ± 0.32[c]
	2020	615	4.29 ± 0.03[a]	605	9.68 ± 0.11[b]	582	13.60 ± 0.20[b]	568	17.53 ± 0.18[a]	559	20.46 ± 0.20[b]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Region	Oum El Bouaghi	251	4.67 ± 0.03[b]	251	9.84 ± 0.14[a]	251	14.39 ± 0.21[ab]	251	17.09 ± 0.25[a]	251	19.07 ± 0.29[a]
	Constantine	554	4.62 ± 0.04[b]	554	9.52 ± 0.12[a]	519	13.85 ± 0.14[a]	492	18.60 ± 0.19[b]	352	22.51 ± 0.29[b]
	Bordj Bou Arréridj	1800	4.40 ± 0.02[a]	1746	9.88 ± 0.59[a]	1612	14.56 ± 0.99[b]	1506	19.14 ± 0.13[b]	1199	22.19 ± 0.19[b]
	P value		***P*<0.0001**		***P*<0.05**		***P*<0.01**		***P*<0.0001**		***P*<0.0001**

Body weights (BW, W30, W60, W90, W120) are in kilograms (kg). Values are presented as Least Squares Mean ± Standard Error (LSM ± SE). Sample size (N) decreased over time due to mortality or loss of ear tags, resulting in missing data. Different lowercase letters ([a, b, c, d]) within a row indicate significant differences between group means (Tukey's HSD, $P<0.05$). W120 data for 2018 cohort (n = 406) are unavailable due to incomplete data collection

TABLE II
Average daily gain in pre-weaning, post-weaning and overall period: Effects of biological and environmental factors

Trait		ADG_{0-90}		ADG_{90-120}		ADG_{0-120}	
		N	LSM ± SE	N	LSM ± SE	N	LSM ± SE
Overall		2248	159.6 ± 1.08	1796	107.2 ± 1.64	1802	144.7 ± 1.18
Sex	Male	1283	168.2 ± 1.61[b]	936	115.3 ± 2.39[b]	940	154.2 ± 1.76[b]
	Female	1322	150.7 ± 1.40[a]	860	98.4 ± 2.19[a]	862	134.3 ± 1.48[a]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Litter size	Single	1684	167.5 ± 1.40[b]	1107	109.5 ± 2.09[a]	1112	151.1 ± 1.56[b]
	Twin	921	146.5 ± 1.60[a]	689	103.7 ± 2.63[a]	690	134.3 ± 1.71[a]
	P value		***P*<0.0001**		*P*>0.05		***P*<0.0001**
Birth month	August	468	159.1 ± 2.29[a]	425	111.7 ± 3.13[a]	426	146.6 ± 2.10[b]
	September	1537	160.0 ± 1.44[a]	1109	106.1 ± 2.24[a]	1112	145.0 ± 1.63[ab]
	October	467	157.4 ± 2.29[a]	249	103.7 ± 3.32[a]	251	138.0 ± 2.45[a]
	P value		*P*>0.05		*P*>0.05		*P*>0.05
Year of birth	2017	342	139.1 ± 2.58[a]	328	61.4 ± 2.58[a]	328	119.8 ± 2.58[a]
	2018	406	166.5 ± 2.50[b]		–		–
	2019	437	213.5 ± 2.83[c]	310	176.3 ± 2.45[c]	312	202.9 ± 2.50[c]
	2020	615	147.0 ± 1.82[a]	555	95.74 ± 1.82[b]	559	134.7 ± 1.56[b]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Region	Oum El Bouaghi	251	137.9 ± 2.58[a]	251	66.2 ± 3.37[a]	251	120.0 ± 2.30[a]
	Constantine	491	157.4 ± 2.02[b]	352	136.6 ± 4.65[c]	352	149.8 ± 2.29[b]
	Bordj Bou Arréridj	1506	163.9 ± 1.39[b]	1193	107.2 ± 1.79[b]	1199	148.3 ± 1.53[b]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**

Average daily gain (ADG) is in gram per day ($g \cdot d^{-1}$). Values are presented as Least Squares Mean ± Standard Error (LSM ± SE). Sample size (N) decreased over time due to mortality or loss of ear tags, resulting in missing data. Different lowercase letters ([a, b, c]) within a row indicate significant differences between group means (Tukey's HSD, $p < 0.05$). ADG_{0-120} and ADG_{90-120} could not be calculated for 2018 due to missing W120 measurements. ADG_{0-90} values for 2018 are included weighing approximately 12%, weighing more (4.67 ± 0.02 kg vs. 4.12 ± 0.02 kg at birth and 22.81 ± 0.19 kg vs. 20.22 ± 0.21 kg at 120 d (TABLE I). Litter size also influenced ADG (*P*<0.0001), except during the post-weaning period (TABLE II). This suggests that twin lambs exhibit partial compensatory growth during the post-weaning period.

These results confirm the growth penalties associated with twinning especially during pre-weaning period, consistent with findings in Algeria for Ouled Djellal [7, 10] and D'man breeds [8, 9]. Similar patterns have been reported in other regions and breeds, including Timahdite, Béni Guil and Sardi in Morocco [11, 21, 23], Tunisian breeds [20], Kajli in Pakistan [14], Washera and Adilo breeds in Ethiopia [3, 30], Dwarf sheep in West Africa [26], Balouchi in Iran [28], Djallonke in Benin [4], Icelandic sheep breed [5] and the Sabi, Dorper and Merino sheep in Zimbabwe [25, 27].

The recurring growth disadvantage observed in twins likely reflects intrauterine competition for nutrients and reduced milk intake during the early stages of life. These constraints suggest that management practices such as improved maternal nutrition during late gestation, early weaning, and cross-fostering may help mitigate growth limitations and enhance overall flock productivity.

Effect of birth month

Birth month had a significant effect on BW (*P*<0.0001) and W30 (*P*<0.05) (TABLE I). Lambs born in October were the heaviest at birth (4.64 ± 0.04 kg), while those born in August were the heaviest at 30 d (10.04 ± 0.12 kg). This may be attributed to better maternal milk production and pasture availability during these months. No significant differences were observed in later weights or in ADG (TABLE II), suggesting that lambs born later in the season experienced partial compensatory growth due to adaptation to the management practices in the study region, where the animals are kept under permanent housing protected from both cold and summer heat [9].

Although the present analysis focused on birth month rather than season, the patterns align with previous studies on seasonal effects on lamb growth. In Algeria, Bendiab and Dekhili [8] and Boubakeur *et al*. [9] noted faster growth in autumn-born lambs, while Zidane *et al*. and Deghnouche *et al*. [10, 19] observed higher performance in spring-born lambs. Similar results in other regions, where lambs born during periods of abundant forage grew faster [3, 4, 15, 29, 30]. These differences reflect climatic variations, forage availability, and management practices that influence both prenatal and postnatal growth.

Effect of year of birth

The year of birth had a significant effect on all growth traits (*P*<0.0001) (TABLES I and II). This analysis included only records from Bordj Bou Arréridj, the only site with complete annual data, and therefore reflects conditions specific to that region. Lambs born in 2019 showed the best performance, whereas those born in 2017 performed the poorest. At 120 d, lambs from 2019 were 47% heavier than those from 2017 (22.2 kg vs. 12.1 kg). A similar pattern was observed for growth rates: ADG_{0-90} was about 50% higher in 2019 than in 2017 (176.3 vs. 117.2 g·d^{-1}), while ADG_{90-120} in 2019 (176.3 g·d^{-1}) was nearly three times that recorded in 2017 (61.4 g·d^{-1}).

Favourable rainfall in 2019 likely improved ewe nutrition, body condition, and milk production. In contrast, 2017 and 2020 were characterized by drought and forage scarcity. Overall, these differences highlight the strong influence of annual climatic variation, pasture availability, and feeding conditions.

Similar year effects have been reported in Morocco [21, 23], Mexico [15], India [13, 24], Benin [4], Ethiopian [3], Zimbabwe [25], Iran [28], and Pakistan [14]. In these studies, annual variations in growth were mainly attributed to differences in forage availability and climatic conditions.

Effect of farm location (Wilaya)

Farm location had a significant effect on all growth traits (TABLES I and II). Lambs born in Oum El Bouaghi (4.67 ± 0.03 kg) and Constantine (4.62 ± 0.04 kg) were the heaviest at birth, which may reflect better maternal nutrition.

After 60 d, lambs from Bordj Bou Arréridj consistently outperformed those from the other locations, reaching 19.14 ± 0.13 kg at 90 d and 22.19 ± 0.19 kg at 120 d, suggesting more favourable feeding management practices in that region. Constantine showed higher ADG (136.6 ± 4.65 g·d^{-1}), followed by Bordj Bou Arréridj. The performance differences between regions may be directly linked to management and feeding practices rather than geography, given that all regions share a similar semi-arid climate. These results suggest that nutrition and health management should be adjusted to regional conditions. Comparable findings have been reported in Algerian flocks [17] and Ethiopian Washera and Adilo lambs [3, 30].

Effects of factor interactions

As biological and environmental factors tend to act together rather than separately, the combined effects of these factors were examined in more detail using interaction analyses. Only significant interactions are presented.

Interaction between Sex and litter size

The interaction between sex and litter size had a significant effect on all growth traits (*P*<0.0001) (TABLES III and IV).

Male singletons were the heaviest at birth (4.46 ± 0.04 kg) and at 120 d (23.76 ± 0.27 kg) and they also exhibited the highest growth rates (173.5 g·d^{-1} from 0 to 90 d and 116.8 g·d^{-1} from 90 to 120 d). In contrast, female twins recorded the lowest values. Overall, singletons outperformed twins and males outperformed females, confirming the combined effect of both factors on early growth.

These results reflect well-known biological mechanisms. Singletons experience less intrauterine competition and greater postnatal milk intake, enhancing nutrient availability and early growth. Meanwhile, males exhibited higher growth potential due to androgen-driven muscle development, greater growth hormone activity, and improved feed efficiency.

Comparable findings have been reported in Sardi [21], Icelandic sheep [5], and Washera sheep [3], and Sabi, Dorper and Merino sheep [25]. These results suggest that the observed interaction

TABLE III
Effect of biological and environmental factor interactions on lambs weights from birth to 120 days

interaction		BW		W30		W60		W90		W120	
		N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE	N	LSM±SE
Sex * Litter size	Male singleton	890	4.46 ± 0.04^{c}	872	10.48 ± 0.09^{d}	831	15.41 ± 0.14^{d}	779	20.29 ± 0.19^{c}	641	23.76 ± 0.27^{c}
	Male twin	393	3.92 ± 0.06^{b}	386	9.47 ± 0.13^{b}	375	13.81 ± 0.18^{b}	367	18.37 ± 0.25^{b}	299	21.54 ± 0.37^{b}
	Female singleton	794	4.42 ± 0.04^{c}	771	10.11 ± 0.08^{c}	676	14.77 ± 0.14^{c}	623	18.97 ± 0.18^{b}	471	21.51 ± 0.27^{b}
	Female twin	528	3.51 ± 0.05^{a}	522	8.43 ± 0.09^{a}	500	12.6 ± 0.13^{a}	480	16.45 ± 0.18^{a}	391	19.21 ± 0.24^{a}
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Sex * Year of birth	Male 2017	207	4.23 ± 0.08^{bcd}	203	8.97 ± 0.13^{b}	203	12.61 ± 0.22^{b}	203	18.1 ± 0.32^{c}	203	20.29 ± 0.42^{bc}
	Male 2018	193	4.34 ± 0.09^{cd}	185	10.31 ± 0.16^{c}	162	15.93 ± 0.27^{d}	124	19.92 ± 0.38^{d}		–
	Male 2019	209	4.57 ± 0.08^{d}	204	11.51 ± 0.16^{d}	198	18.44 ± 0.27^{f}	191	24.86 ± 0.38^{f}	180	30.28 ± 0.43^{e}
	Male 2020	274	3.99 ± 0.08^{abc}	266	10.58 ± 0.18^{c}	256	14.36 ± 0.21^{c}	252	18.7 ± 0.29^{cd}	250	21.70 ± 0.34^{c}
	Female 2017	135	3.88 ± 0.11^{ab}	125	7.71 ± 0.13^{a}	125	10.43 ± 0.22^{a}	125	15 ± 0.32^{a}	125	16.27 ± 0.42^{a}
	Female 2018	213	3.79 ± 0.09^{a}	201	9.53 ± 0.14^{b}	181	14.95 ± 0.24^{cd}	142	18.71 ± 0.32^{cd}		–
	Female 2019	228	4.23 ± 0.08^{bcd}	223	10.93 ± 0.15^{cd}	161	17.1 ± 0.29^{e}	153	22.44 ± 0.36^{e}	132	26.98 ± 0.42^{d}
	Female 2020	341	3.85 ± 0.07^{a}	339	8.97 ± 0.11^{b}	326	13 ± 0.16^{b}	316	16.6 ± 0.21^{b}	309	19.47 ± 0.23^{b}
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Sex * Birth month	Male August	204	4.07 ± 0.09^{ab}	204	10.93 ± 0.22^{d}	204	14.80 ± 0.26^{bc}	204	19.59 ± 0.35^{b}	196	23.34 ± 0.43^{c}
	Male September	776	4.28 ± 0.04^{bc}	772	9.96 ± 0.09^{bc}	763	14.98 ± 0.15^{c}	728	19.76 ± 0.20^{b}	603	23.15 ± 0.29^{c}
	Male October	303	4.47 ± 0.07^{c}	282	10.2 ± 0.17^{c}	239	14.81 ± 0.23^{bc}	214	19.46 ± 0.31^{b}	141	22.27 ± 0.46^{bc}
	Female August	273	3.92 ± 0.07^{a}	271	9.39 ± 0.13^{a}	268	13.99 ± 0.22^{ab}	255	18.01 ± 0.28^{a}	238	20.90 ± 0.33^{ab}
	Female September	761	4.01 ± 0.04^{a}	758	9.41 ± 0.09^{ab}	686	13.87 ± 0.14^{a}	662	17.82 ± 0.17^{a}	509	20.35 ± 0.26^{a}
	Female October	288	4.33 ± 0.08^{bc}	264	9.56 ± 0.17^{ab}	222	13.61 ± 0.21^{a}	186	17.88 ± 0.29^{a}	115	20.10 ± 0.37^{a}
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Birth month * Year of birth	August 2018	19	4.23 ± 0.28^{ab}	19	11.06 ± 0.58^{c}	19	17.60 ± 1.01^{ef}	19	21.99 ± 1.10^{c}	–	–
	August 2019	31	4.14 ± 0.22^{ab}	31	10.87 ± 0.43^{c}	31	17.43 ± 0.85^{de}	28	24.40 ± 0.91^{cd}	27	29.58 ± 1.01^{d}
	August 2020	344	3.86 ± 0.07^{a}	342	10.06 ± 0.16^{bc}	339	13.93 ± 0.19^{bc}	329	18.04 ± 0.26^{a}	324	20.97 ± 0.29^{b}
	September 2017	297	4.07 ± 0.07^{ab}	297	8.33 ± 0.10^{a}	297	11.48 ± 0.18^{a}	297	16.48 ± 0.25^{a}	297	18.18 ± 0.33^{a}
	September 2018	302	3.91 ± 0.07^{a}	302	9.73 ± 0.11^{bc}	299	15.33 ± 0.19^{cd}	247	19.07 ± 0.25^{ab}	–	–
	September 2019	376	4.39 ± 0.06^{ab}	370	11.12 ± 0.12^{c}	303	17.72 ± 0.21^{ef}	300	23.63 ± 0.30^{cd}	283	28.84 ± 0.34^{d}
	September 2020	160	3.79 ± 0.10^{a}	159	9.25 ± 0.17^{ab}	148	13.06 ± 0.23^{ab}	144	16.57 ± 0.29^{a}	144	19.50 ± 0.34^{ab}
	October 2017	41	4.26 ± 0.18^{ab}	27	10.24 ± 0.24^{bc}	27	15.10 ± 0.37^{bc}	27	21.81 ± 0.51^{bc}	27	25.22 ± 0.66^{c}
	October 2018	85	4.50 ± 0.13^{ab}	65	10.38 ± 0.29^{bc}	25	14.76 ± 0.82^{bc}	–	–	–	–
	October 2019	30	4.74 ± 0.24^{b}	26	12.82 ± 0.48^{d}	25	19.78 ± 0.67^{f}	16	25.62 ± 1.05^{d}	–	–
	October 2020	111	4.24 ± 0.11^{ab}	104	9.06 ± 0.20^{ab}	95	13.25 ± 0.30^{abc}	95	17.22 ± 0.38^{a}	91	20.18 ± 0.38^{ab}
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Birth month * Litter size	Singleton August	237	4.46 ± 0.08^{cd}	237	10.93 ± 0.18^{d}	235	15.39 ± 0.25^{b}	229	20.21 ± 0.32^{b}	214	23.49 ± 0.38^{c}
	Singleton September	1057	4.34 ± 0.04^{c}	1053	10.07 ± 0.07^{c}	991	15.07 ± 0.12^{b}	940	19.59 ± 0.17^{b}	745	22.74 ± 0.25^{c}
	Singleton October	390	4.69 ± 0.06^{d}	353	10.61 ± 0.14^{cd}	281	15.10 ± 0.21^{b}	233	19.68 ± 0.29^{b}	153	22.18 ± 0.41^{bc}
	Twin August	240	3.52 ± 0.07^{a}	238	9.19 ± 0.14^{b}	237	13.3 ± 0.20^{a}	230	17.23 ± 0.29^{a}	220	20.55 ± 0.36^{ab}
	Twin September	480	3.71 ± 0.05^{ab}	477	8.84 ± 0.11^{ab}	458	13.12 ± 0.16^{a}	450	17.27 ± 0.22^{a}	367	20.09 ± 0.32^{a}
	Twin October	201	3.85 ± 0.09^{b}	193	8.58 ± 0.18^{a}	180	12.87 ± 0.22^{a}	167	17.39 ± 0.3^{a}	103	19.97 ± 0.43^{a}
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Birth month * Litter size * Year	*P* value		*P*>0.05		*P*>0.05		*P*>0.05		*P*>0.05		*P*>0.05
Birth Month * Sex * Year	*P* value		*P*>0.05		***P***<0.001		***P***<0.01		***P***<0.01		***P***<0.05
Litter size * Sex * Year	*P* value		*P*>0.05		*P*>0.05		*P*>0.05		*P*>0.05		*P*>0.05

Body weights (BW, W30, W60, W90, W120) are in kilograms (kg). Values are presented as Least Squares Mean ± Standard Error (LSM ± SE). Sample size (N) decreased over time due to mortality or loss of ear tags, resulting in missing data. Different lowercase letters ($^{a, b, c, d, e, f}$) within a row indicate significant differences between group means (Tukey's HSD, *P*<0.05). W120 data for 2018 cohort (n = 406) are unavailable due to incomplete data collection

TABLE IV
Effect of biological and environmental factor interactions on average daily gains in pre-weaning, post-weaning and overall period

Interaction		ADG_{0-90}		ADG_{90-120}		ADG_{0-120}	
		N	**LSM ± SE**	**N**	**LSM ± SE**	**N**	**LSM ± SE**
Sex * Litter size	Male singleton	779	173.5 ± 1.99[c]	637	116.8 ± 2.82[b]	641	158.9 ± 2.16[c]
	Male twin	367	157.0 ± 2.67[b]	299	112.2 ± 4.45[b]	299	144.1 ± 2.97[b]
	Female singleton	623	160.2 ± 1.91[b]	470	99.5 ± 3.06[a]	471	140.5 ± 2.15[b]
	Female twin	479	138.5 ± 1.87[a]	390	97.2 ± 3.11[a]	391	126.8 ± 1.92[a]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Sex * Year of birth	Male 2017	203	150.8 ± 3.34[bc]	203	73.1 ± 3.34[b]	203	131.4 ± 3.34[b]
	Male 2018	124	171.9 ± 3.80[d]		–		–
	Male 2019	191	224.0 ± 4.01[f]	179	183.7 ± 3.35[e]	180	213.5 ± 3.41[e]
	Male 2020	252	158.8 ± 2.97[cd]	247	100.3 ± 3.41[c]	250	144.1 ± 2.65[c]
	Female 2017	125	120.2 ± 3.43[a]	125	42.4 ± 3.43[a]	125	100.7 ± 3.43[a]
	Female 2018	142	161.8 ± 3.29[cd]		–		–
	Female 2019	153	200.4 ± 3.67[e]	131	166.3 ± 3.38[d]	132	188.3 ± 3.24[d]
	Female 2020	316	137.7 ± 2.13[b]	308	92.5 ± 1.80[c]	309	127.1 ± 1.72[b]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Sex * Birth month	Male August	204	168.4 ± 3.59[b]	196	129.9 ± 4.91[b]	196	157.6 ± 3.37[c]
	Male September	728	168.9 ± 2.13[b]	601	113.3 ± 3.11[ab]	603	154.8 ± 2.37[c]
	Male October	214	165.6 ± 3.24[b]	139	103.6 ± 5.27[a]	141	146.7 ± 3.64[bc]
	Female August	254	153.1 ± 2.92[a]	237	97.3 ± 3.74[a]	238	138.7 ± 2.56[ab]
	Female September	662	150.1 ± 1.82[a]	508	97.4 ± 3.17[a]	509	133.3 ± 2.08[ab]
	Female October	186	149.2 ± 3.12[a]	115	105.2 ± 3.52[a]	115	129.6 ± 3.00[a]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Birth month * Year of birth	August 2018	19	194.2 ±10.8[cde]	–	–	–	–
	August 2019	28	222.3 ± 9.31[ef]	27	175.2 ± 10.61[c]	27	210.1 ± 7.81[d]
	August 2020	329	153.0 ± 2.61[ab]	323	94.0 ± 2.65[b]	324	139.1 ± 2.26[b]
	September 2017	297	134.4 ± 2.64[a]	297	56.7 ± 2.64[a]	297	115.0 ± 2.64[a]
	September 2018	247	164.4 ± 2.52[bc]	–	–	–	–
	September 2019	300	211.7 ± 3.07[def]	281	176.9 ± 2.49[c]	283	202.2 ± 2.65[d]
	September 2020	144	137.2 ± 2.85[ab]	143	98.6 ± 2.68[b]	144	127.3 ± 2.53[ab]
	October 2017	27	191.5 ± 5.11[cd]	27	113.7 ± 5.11[b]	27	172.0 ± 5.11[c]
	October 2019	16	230.9 ± 10.43[f]	–	–	–	–
	October 2020	95	141.3 ± 4.00[ab]	89	97.3 ± 4.28[b]	91	130.5 ± 3.06[ab]
	P value		***P*<0.0001**		***P*<0.0001**		***P*<0.0001**
Birth month * Litter size	Singleton August	229	172.7 ± 3.28[b]	214	116.6 ± 4.54[a]	214	156.9 ± 3.01[c]
	Singleton September	940	166.6 ± 1.78[b]	742	108.0 ± 2.69[a]	745	150.9 ± 2.05[bc]
	Singleton October	233	166.0 ± 3.05[b]	151	106.2 ± 4.47[a]	153	144.3 ± 3.34[abc]
	Twin August	229	147.2 ± 3.01[a]	219	107.6 ± 4.27[a]	220	137.8 ± 2.85[ab]
	Twin September	450	146.0 ± 2.28[a]	367	101.9 ± 4.01[a]	367	133.0 ± 2.55[a]
	Twin October	167	146.8 ± 3.29[a]	103	101.6 ± 4.79[a]	103	131.2 ± 3.49[a]
	P value		***P*<0.0001**		*P*>0.05		***P*<0.0001**
Birth month * Litter size * Year	*P* value		*P*>0.05		***P*<0.05**		*P*>0.05
Birth Month * Sex * Year	*P* value		***P*<0.01**		*P*>0.05		***P*<0.05**
Litter size * Sex * Year	*P* value		*P*>0.05		***P*<0.05**		*P*>0.05

Average daily gain (ADG) is in gram per day ($g \cdot d^{-1}$). Values are presented as Least Squares Mean ± Standard Error (LSM ± SE). Sample size (N) decreased over time due to mortality or loss of ear tags, resulting in missing data. Different lowercase letters ([a, b, c, d, e, f]) within a row indicate significant differences between group means (Tukey's HSD, *P*<0.05). ADG_{0-120} and ADG_{90-120} could not be calculated for 2018 due to missing W120 measurements. ADG_{0-90} values for 2018 are included largely reflects the additive effects of reduced foetal competition and the inherent growth advantage of males.

Interaction between sex and birth month

The interaction between sex and birth month significantly affected all growth traits (P<0.0001; TABLES III and IV). Males born in October had the highest birth weights, while females born in August had the lowest. At 60 and 120 d, males born in August and September reached the greatest body weights, while females born in September and October showed the lowest. Overall, males exhibited higher ADG than females across all months, with the largest sex differences observed in August and September. Male lambs born in August demonstrated the best performance (129.94 ± 4.91 $g \cdot d^{-1}$ from 90 to120 d; 157.59 ± 3.37 $g \cdot d^{-1}$ overall), whereas female lambs born in September and October recorded the lowest gains (133.3 ± 2.08 $g \cdot d^{-1}$ and 138.7 ± 2.56 $g \cdot d^{-1}$, respectively).

These results suggest that environmental and nutritional stress during late summer and early autumn lambing amplifies sex differences, with males growing faster and adapting better than females. Zidane *et al*. [10] reported similar results which highlights the role of environmental conditions in modulating sexual dimorphism in lamb growth. Whereas Chopra *et al*. [6] found no significant effect for this interaction.

Interaction between sex and year of birth

Sex and year of birth interaction had a significant influence on all growth traits (P<0.0001; TABLES III and IV). Males born in 2019 showed the best performance, with an average birth weight of 4.57 ± 0.08 kg, an average weight of 30.28 ± 0.43 kg at 120 d, and an overall ADG of 213.52 ± 3.41 $g \cdot d^{-1}$. In contrast, females born in 2017 performed the poorest. Across all years, males outperformed females, although the magnitude of this difference depended on environmental conditions. The performance gap widened in years with favourable rainfall and forage availability, such as 2019, reflecting better ewe nutrition and milk production. Conversely, under drought conditions (in 2017 and 2020), growth rates declined and sex differences narrowed.

Similar interactions between sex and year have been reported in Morocco [11, 21], Zimbabwe [25]. These studies all show that favourable years amplify sex differences in growth performance. These findings confirm that male growth potential is more fully expressed under optimal climatic and nutritional conditions. Chopra *et al*. [6] found no significant effect for this interaction.

Interaction between birth month and litter size

As shown in TABLES III and IV, the interaction between birth month and litter size had a significant effect on all growth traits (P<0.0001). Singleton lambs consistently outperformed twins across all months. The heaviest lambs were singletons born in October (4.69 ± 0.06 kg), while those born in August had the highest weights at 30 and 120 d (10.93 ± 0.18 kg and 23.49 ± 0.38 kg, respectively) and exhibited the fastest growth rate (172.7 ± 3.28 $g \cdot d^{-1}$ from birth to 90 d; 156.9 ± 3.01 $g \cdot d^{-1}$ overall).

In contrast, twins born in August had the lowest birth weights (3.52 ± 0.07 kg), and those born in September and October remained lighter at later stages (17.2–17.4 kg at 90 d and approximately 20.0 kg at 120 d), with the slowest growth (146 ± 2.28 $g \cdot d^{-1}$ from birth to 90 d; 131.2 ± 3.49 $g \cdot d^{-1}$ overall).

These results suggest that singletons born in August experienced the fastest growth rates, reflecting reduced intrauterine competition and greater milk availability. In contrast, twins, particularly those born in September and October, exhibited slower growth rates until weaning. This suggests that late-summer nutritional constraints in late summer intensify the disadvantage of twins, whereas singletons benefit more from a favourable early-season milk supply.

These findings align with those reported by Zidane *et al*. [10]; confirming that twin lambs are more sensitive to seasonal feed limitations in semi-arid environments.

Interaction between birth month and year of birth

The interaction between birth month and year of birth had a significant effect on all growth traits (P<0.0001) (TABLES III and IV). Lambs born in October 2019 demonstrated the best performance, with the highest birth weight (4.74 ± 0.24 kg), W90 (25.62 ± 1.05 kg), and the fastest pre-weaning growth rate (230.9 ± 10.43 $g \cdot d^{-1}$). At 120 d, lambs born in August and September 2019 remained the heaviest (29.58 ± 1.01 kg and 28.84 ± 0.34 kg, respectively), and had the highest overall ADG (210.1 ± 7.81 $g \cdot day^{-1}$ and 202.2 ± 2.65 $g \cdot d^{-1}$, respectively).

In contrast, lambs born in September 2017 demonstrated the poorest performance throughout the growth period, reaching 18.18 ± 0.33 kg at 120 d and growth of 115.0 ± 2.64 $g \cdot d^{-1}$. Similarly, lambs born in August and September 2020 also grew below average (20.97 ± 0.29 kg; 139.1 ± 2.26 $g \cdot d^{-1}$ and 19.50 ± 0.34 kg; 127.3 ± 2.53 $g \cdot d^{-1}$, respectively).

Overall, lambs born in 2019 clearly outperformed those from other years, reflecting highly favourable environmental and nutritional conditions. Conversely, lambs born in 2017 and 2020 when there was a drought and feed scarcity, showed reduced growth. confirming that interannual and seasonal climatic variability strongly influence lamb performance. Similar patterns have been reported by Chopra *et al.* [6] where the combined effects of birth period and year determine growth trajectories.

Analysis of three-way interactions revealed variable limited but significant effects on lamb growth (TABLES III and IV). For body weights from birth to 120 d, the interaction between birth month, litter size and year of birth and the interaction between litter size, sex and year of birth were not significant (P>0.05). However, the interaction between birth month, sex and year significantly affected weights at 30 d (P<0.001), 60, 90 d (P<0.01) and 120 d (P<0.05). Regarding growth rate, the interactions between birth month, litter size and year and the interaction between litter size, sex and year were significant only during the post-weaning period (P<0.05).

In contrast, the interaction between birth month, sex and year significantly influenced growth in the pre-weaning period (P<0.01) and overall ADG (P<0.05). Similar studies on three way interactions were conducted elsewhere: Chopra *et al*. [6] found no significant effect for the interaction season, sex and year while Assan and Makuza [25] noted a significant effect of the interaction between sex, litter size and year on birth weight and weaning weight.

Interestingly, while three-way interactions were generally less consistent than two-way effects, some combinations of sex and birth month across different years still appeared to influence growth, especially during the early stages of growth.

CONCLUSIONS

This study confirms that the pre-weaning growth in Ouled Djellal lambs raised in northeastern Algeria is strongly influenced by both biological and environmental factors. Sex and litter size were the main biological determinants, with males and single-born lambs consistently outperforming females and twins. Among environmental factors, birth month, year, and region significantly affected growth performance, while the superior performance observed in 2019 highlighted the major influence of climatic conditions and feed availability.

The results emphasize the importance of improving nutritional management during late gestation and early lactation, particularly for twin-bearing ewes. They also suggest that aligning lambing periods with favourable forage availability and adapting feeding strategies to annual climatic variation may improve lamb growth under semi-arid conditions.

Overall, improving growth performance in these production systems requires an integrated approach combining appropriate nutrition, adapted management practices, and consideration of non-genetic factors in breeding and production strategies.

Conflict of interest

The authors declare no conflict of interest.

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