A comprehensive analysis of lactation traits in the Arbia goat breed (*Capra hircus*) from Algeria

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A comprehensive analysis of lactation traits in the Arbia goat breed (*Capra hircus*) from Algeria

Abstract

This study aimed to analyze the milk performance of Arbia does, the predominant goat breed in Algeria. A total of 389 quantitative and qualitative milk control records were collected from sixty-six dairy Arbia does monitored throughout their complete lactation period. The animals, managed under similar livestock practices, were located in two different agroecological regions: arid (Ar) and semiarid (SAr). The days in milk (DIM) and kidding interval (KI) were 195.82 ±60.42 and 250.55 ±69.55 days, respectively, with milk production peaking at 89.22 ±10.76 days postkidding. The study recorded an average Total Milk Yield (TMY) of 207.18 ±76.86 kg, Daily Milk Yield (DMY) of 1.05 ±0.2 kg, and persistence coefficient (PC) of 72.91 ±4.13 %. The average Total Fat Yield (TFY), Total Protein Yield (TPY), Milk Fat Rate (MFR), and Milk Protein Rate (MPR) were 219.72 ±95.05 g, 745.28 ±88.68 g, 1.94 ±1.13 %, and 4.11 ±1.67%, respectively. Does from SAr produced more TFY and comparable TPY compared to those from Ar, despite having lower TMY and shorter DIM, reflecting significantly higher MFR and MPR in SAr. While lactation length showed potential influence on TMY ($P = 0.07$) and significant effects on TPY ($P < 0.05$), other factors, such as age, lactation number, and animals' origin, did not significantly affect TMY. Analysis revealed one production profile in Ar and two distinct lactation production profiles in SAr, suggesting the need for tailored optimization strategies based on this diversity in milk production characteristics.

Keywords: Fat Rate; Goat; Lactation traits; Lactation curve; Milk production; Protein rate.

Study contribution:

This study provides the first detailed overview of milk production and lactation in the Arbia goat, Algeria's main dairy breed. It shows how different environmental conditions affect milk quantity, quality, and the length of lactation, revealing clear regional differences. Milk fat and protein levels, as well as lactation duration, vary with the environment, reflecting the breed's ability to adapt. Importantly, the study finds that the length of lactation has a greater impact on total milk production than the goat's age or number of previous lactations. By highlighting these differences, the research offers valuable insights for designing local management and breeding strategies, helping to improve sustainable dairy production while conserving this uniquely adapted breed.

Introduction

Domestic animal genetic resources significantly contribute to the country's domestic production, and sustainable agricultural development should rely on the valorization of biodiversity through the improvement of local genetic resources.[(1)] Counting 5 120 824 heads, the Algerian goats population represents, after sheep (31 192 020 heads), the most important group of ruminants.[(2)] Goat farming constitutes an important economic activity for breeders in small-holder production systems. It is mainly concentrated in mountainous, steppe, and sub-desert areas[(3, 4),] and the Algerian Arbia goat breed, ethnically related to the Nubian breed, is the most dominant population.[(5)] This breed has a multicolored coat (black, gray, brown) with long hair measuring 12–15 cm,[(5–7)] and it is characterized by its small size (50–70 cm), and a hornless head with long, wide, and pendulous ears.[(5, 8)]

Meat is the primary product from goat breeding in Algeria, with a production of 19 243.84 tons.(2) The production of goat milk in Algeria is estimated at 324 463.67 tons and is mainly consumed by the breeders and their families.(2, 4) Its industrial valorization has seen remarkable development in recent years, but still often remains at the traditional scale.(9, 10) Cow's milk represents 76 % of the national production, with the remaining 24 % attributed to camel and goat milk.(11) This modest productivity is attributed to the feeding system, which is primarily based on grazing.(12–14) Additionally, the absence of standard genetic improvement programs and unregulated crossbreeding exacerbate this situation.(7) Algeria's need to increase internal milk production led to efforts that did not adequately consider these animals' adaptation to local environmental conditions; as a result, attempts to increase milk production were unsuccessful.(15)

Research on milk production profiles of dairy animals has been conducted using various methods that describe the biological processes of milk production.(16–19) The improvement of milk production pathways has been traditionally based on evaluation systems such as progeny testing, sire evaluation, and dam-daughter comparisons.(20) Modeling the shape of the curve from elementary controls,(21–23) as well as methods such as principal component analysis (PCA), are very comprehensive approaches for analyzing multiple milk production traits simultaneously.(24, 25) Their assumption-free nature and computational efficiency make it particularly suitable for exploring complex datasets, revealing underlying patterns and relationships without the need for labeled data.(26) Additionally, PCA's feature extraction capabilities allow for the creation of new features that capture the most relevant information, enhancing subsequent modeling tasks.

This study aimed to collect data about milk production of Arbia breed goat and in particular to: (1) investigate the milk performance and lactation curve characteristics; (2) evaluate the effects of various factors such as age, origin, lactation number, and lactation duration on average milk, fat, and protein production per lactation; (3) classify the Arbia goat population based on their lactation traits.

Materials and methods

Ethical statement

The animals were studied according to the ethical principles of animal experimentation and international guidelines for animal welfare (Terrestrial Animal Health Code 2018, section 7. Art 7.5.1) and national executive decree No. 95-363 of November 11, 1995 (Algeria).

Study area

The study was conducted in two different regions: Souk Ahras and Biskra (**Figure 1**). Souk Ahras is characterized by a hot and dry summer and a cold and humid winter. The annual precipitation in this region reaches 650 mm in the north and 350 mm in the south. Significant snowfall occurs during the winter, with temperatures ranging between 1–15 °C in winter and between 25–32 °C in summer. The sirocco and northwest winds blow over Souk Ahras. As for Biskra, it has a hot Mediterranean climate with a dry summer according to the *Köppen-Geiger* classification. The average temperature in Biskra over the year is 22.4 °C, and the average precipitation is 195.9 mm.

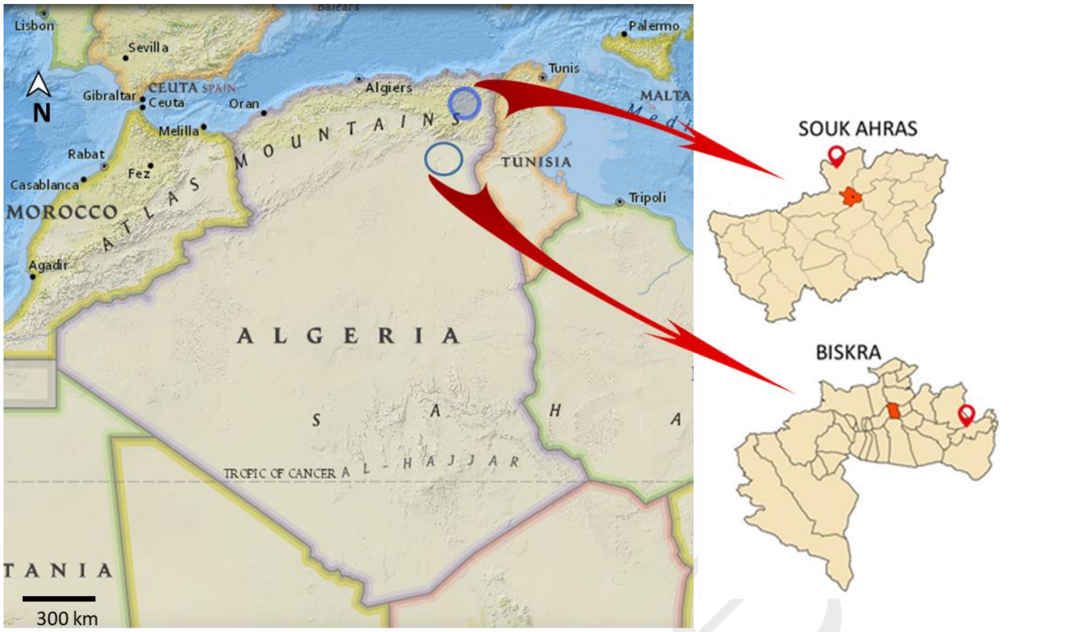

Figure 1. The geographical locations of the two study areas: Souk Ahras and Biskra.

Animals

The study was conducted over a period of eight months, from March (the kidding month) to August, and involved 66 unrelated goats sourced from two farms located in Souk Ahras (n = 32) and Biskra (n = 34). All animals belonged to the local Arbia breed and were raised in a family farming system under semi-extensive management conditions (**Figure 2**). A preliminary clinical examination confirmed that all goats were in good health and free from any apparent disease. The animals ranged in age from 1 to 5 years and were distributed according to their lactation order as follows: first lactation (n = 11), second (n = 24), third (n = 18), fourth (n = 9), and fifth (n = 4). Farming practices were similar across both study sites.

The goats were kept in open-air enclosures with straw bedding and static ventilation. They grazed daily on natural pasture and received a supplemental ration of

150 grams of concentrate feed per animal. Water and feed were provided collectively each evening upon their return from grazing. The goats were not synchronized for breeding (two breeding periods: spring and autumn) and were bred naturally with a ratio of 1 buck per 7 does throughout the year. Milk was manually collected once a day, in the morning.

Figure 2. Algerian indigenous goat of Arbia breed.

Data collection and laboratory analysis

The milk control was conducted regularly every 26-33 days in an unpredictable manner for the farmer. The first control was carried out within the interval of 5 to 38 days after kidding. A total of 389 quantitative controls were performed and conducted simultaneously with milk sampling for physicochemical analysis. Individual animal milk samples were placed at 4 °C and transported under a cold chain to the laboratory, where they are analyzed within 24 hours. The following physicochemical quality parameters were measured using a LACTOSCAN® SAP 50 calibrated using the Gerber method for fat content and the Bradford method for protein content.(19)

Lactation traits and reproductive performances

The lactation traits and the reproductive performances were evaluated through the parameters described below.(27–30) The duration of lactation: days in milk (DIM in days), calculated by adding the periods between the onset of lactation and the initial assessment, subsequent assessments, and the final assessment before the end of lactation (during drying off), as provided by the breeders and documented in the survey conducted on the farms under investigation. Milk recording was carried out during the milking-only period in accordance with the guidelines of the International Committee for Animal Recording for dairy sheep milk recording.(28) Dairy performance was monitored through monthly tests, following the protocol of the official control system of the AC-coded type.(29) This procedure involved recording individual and total milk yields during the first milking, along with total production during the second milking within a 24-hour cycle.

Milk volume was measured at morning milking, and the morning-to-evening yield ratio was used to estimate the individual daily milk yield. Total milk yield (TMY), expressed in kilograms, was calculated using Fleischmann's method.(27, 29) Specifically, TMY was computed by multiplying the first interval by the milk yield recorded at the initial assessment, each subsequent interval by the average yield of the two corresponding assessments, and the final interval (from the last control to drying-off) by the yield observed at the last assessment. The sum of these products provided the estimate of the TMY.

$$\text{TMY} = NC1 + i1\left[\frac{(C+C2)}{2}\right] + \cdots + i(n-1)\left[\frac{(Cn-1+Cn)}{2}\right] + pC$$

N: Number of days between calving and Control 1 (C1).

C1: First control.

C2: Second control.

Cn: Last control.

Cn-1: Second-to-last control.

i1: Days between C1 and C2.

i(n-1): Days between the second-to-last control and the last control.

p: Days between the last control and drying off.

Total fat yield (TFY) and total protein yield (TPY) in grams were calculated by using the same methodology for computing total milk yield per lactation. Indeed, TFY and TPY were computed by multiplying the interval between kidding and first control by the fat rate/protein rate recorded at the initial assessment, each subsequent interval by the average fat/protein rate of the two corresponding assessments, and the final interval (from the last control to drying-off) by the fat/protein rate observed at the last assessment. Percentages of milk fat rate (MFR) and milk protein rate (MPR in %) were calculated, respectively, as the average of the total quantity of fat and protein produced per lactation divided by the total quantity of milk per lactation of each animal.

The total butter quantity, butter yield (BY) was estimated to be 85 % of the total fat quantity yielded per lactation and per animal.[31] Daily milk yield (DMY) in kilograms was determined by dividing TMY by the DIM. The persistence coefficient (PC) was calculated as follows in order to evaluate the animals' ability to keep a high level of milk output following the initial peak of lactation over time.[19] Essentially, it gauges the capacity of an animal.

$$\mathrm{PC} = \frac{100}{n}\left[\left(\frac{P1}{Pmax}\right) + \left(\frac{P2}{P1}\right) + \left(\frac{P3}{P2}\right) + \cdots + \left(\frac{Pn}{Pn-1}\right)\right]$$

n: Number of controls.

Pmax: Maximum production (peak).

P1: Production at the 1st control.

P2: Production at the 2nd control.

P3: Production at the 3rd control.

Pn: Production at the last control.

Pn-1: Production at the penultimate control.

Utilizing the "test-day records" from milk recordings, individual lactation curves were generated, providing a depiction of the daily milk production over time. The average lactation curve identified several key parameters, including DIM, TMY, maximum production (Peak), time to peak production (tpeak), duration of the ascending phase, duration of the descending phase, slope of the curve during the descending phase, and PC. Kidding interval (KI): the duration between two consecutive kiddings, offering insights into the reproductive cycle of the female goats. Days open (DO): the period known as the calving-to-conception interval, calculated as the timeframe between calving and the subsequent conception of the female goats. This interval is crucial for understanding the reproductive efficiency and fertility of the goat population under study.

Statistical analysis

The collected data were summarized by descriptive statistical analysis (mean, standard deviation, maximum, and minimum). Pearson correlation analysis was conducted to examine the relationships between these lactation traits. The effects of the lactation number and of the breeding herd on the considered lactation traits were evaluated through analysis of variance (ANOVA) after the assessment of the normal distribution through Shapiro-Wilk and Kolmogorov-Smirnov tests. The ANOVA test was followed by Duncan's post hoc test. In addition, a multivariable linear regression analysis was used to investigate the relationship between independent variables (such as origin, age, lactation number, breeding system, and lactation length) and dependent variables such as total milk yield, total fat yield (TFY), and total protein yield (TPY).

The Global Validation of Linear Models Assumptions (gvlma) package in R confirmed that the linear models meet the assumptions of linearity, normality of residuals (Skewness and Kurtosis), and homoscedasticity. A principal component analysis (PCA) was conducted to elucidate various production profiles among the animals under study. The objective of this analysis was to condense the information encompassed by several original lactation trait variables: DIM, TMY, TFY, TPY, MFR, MPR, DMY, BY, PC, and KI into a reduced set of composite variables termed "Principal Components" (PCs), while retaining as much information as possible. Phenotypic correlations, represented by factor loadings, between the PCs and the original lactation traits were also computed. Only PCs with eigenvalues exceeding unity were retained, as they accounted for the majority of data variance.

The principal component scores (indices) assigned to each animal were regarded as potential predictors of lactation performance. Subsequently, all does were categorized into one of three groups based on their PC scores. Milk production performance was then analyzed using one-way ANOVA, with the data segmented into three clusters generated by hierarchical ascending classification (HAC), where the PCs served as independent variables. The analyses were performed using R (version 4.3.3) software. Statistical significance was determined at a threshold of $P < 0.05$.

Results

Lactation length and reproductive performances

Data obtained from lactation control records, encompassing various time intervals such as successive lactation controls, dry period duration, lactation length, days open, and the interval between kidding, are in **Table 1**. The average interval between kidding and the first control was 22.47 ±7.39 days. Successive controls (C2 to C8) occurred at intervals with averages ranging from 23.32 ±0.47 to 33.64 ±1.49 days. The recorded interval between the last control and the beginning of the drying-off period was 25.76 ±8.56 days. Additionally, the mean dry period length was 54.73 ±16.66 days. The average DIM was 195.85 ±60.42 days (**Figure 4**). Furthermore, lactation control encompassed a series of examinations, comprising 4 checks for 32 goats, resulting in an DIM of 136 days. For 11 goats, the examinations were extended to 7 checks, yielding an average lactation duration of 224.63 ±7.54 days. Remarkably, 23 goats continued their lactation until the 8th check, resulting in an average lactation duration of 265.26 ±9.93 days (**Figure 3**).

Table 1. Intervals (days) between kidding and first lactation control of the Arbia dairy goat breed

	N	Mean	SD	Min	Max
K-C1 (days)	66	22.47	7.39	3	41
C1-C2 (days)	66	33.64	1.49	31	35
C2-C3 (days)	66	33.11	1.88	31	35
C3-C4 (days)	66	29.05	3.05	23	32
C4_C5 (days)	34	23.32	0.47	23	24
C5_C6 (days)	34	25.62	2.37	24	29
C6_C7 (days)	34	29.97	1.42	29	32
C7_C8 (days)	23	32.00	0.00	32	32
LC-D (days)	66	25.76	8.56	17	34
D (days)	66	54.73	16.66	44	115
DO (days)	66	91.38	39.73	33	198
KI (days)	66	250.55	69.55	180	346
DIM (jr)	66	195.85	60.42	136	279

K: kidding, C1, C2,.., C8: Control number, D: Dry off, LC: Last control, DIM: Days in Milk, KI: Kidding interval, DO: Days open.

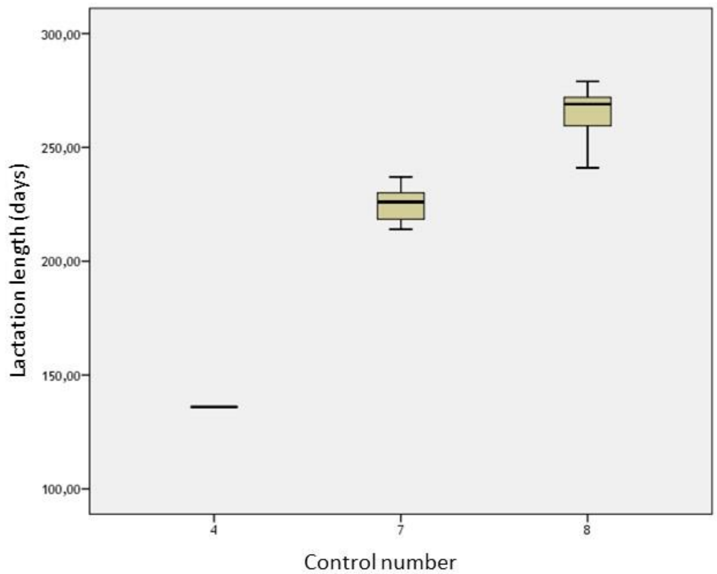

Figure 3. Lactation length in relation to the number of milk controls conducted.

The mean intervals of DO and KI were 91.38 ± 39.73 days and 250.55 ± 69.55 days, respectively (**Table 1**).

Milk yield and lactation persistency coefficient

Table 2 and **Figure 4** show the results of milk production traits monitoring in the studied goats. The average milk yield per goat increased from the initial control (1.16 ±0.62 kg) to the third control (1.77 ±0.5 kg). Peak milk yield was observed approximately on the 89.22 ±10.76th day post-kidding. Subsequently, milk production exhibited a gradual decline, reaching its nadir by the 8^{th} control (**Figure 4**). The overall average TMY per lactation was 207.18 ±76.86 kg, with individual values ranging from 68.00 to 346.73 kg. The mean DMY per animal was 1.05 ±0.20 kg, with the highest and lowest daily averages recorded at 1.49 and 0.50 kg, respectively. The mean persistency coefficient of milk production per lactation ranged between 64.85 % and 82.22 %, with an average of 72.91 ±4.13 %.

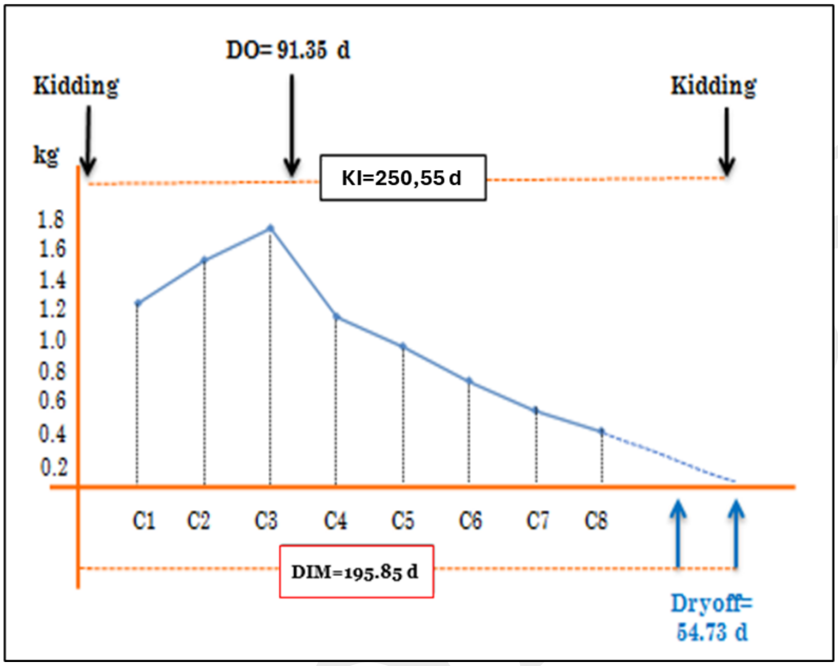

Figure 4. Average lactation curve and reproductive traits of Arbia goat breed (n = 66)

C: Control number, DO: Days open, KI: Kidding interval (days), DIM: Days in milk.

Table 2. Milk yield per control, milk yield between the last control and dry off, total milk yield, daily milk yield, and persistency coefficient of Arbia dairy goat breed

	N	Mean	SD	Min	Max
MY C1 (kg)	66	1.16	0.62	0.50	2.23
MY C2 (kg)	66	1.51	0.57	0.50	2.56
MY C3 (kg)	66	1.77	0.50	0.43	2.93
MY C4 (kg)	66	1.05	0.31	0.43	2.00
MY C5 (kg)	34	0.81	0.27	0.26	1.36
MY C6 (kg)	34	0.53	0.22	0.18	1.00
MY C7 (kg)	34	0.29	0.13	0.04	0.57
MY C8 (kg)	23	0.12	0.06	0.01	0.26
TMY (kg)	66	207.18	76.86	68.00	346.73
DMY (kg)	66	1.05	0.20	0.50	1.49
PC (%)	66	72.91	4.13	64.85	82.22

MY: Milk yield (kg), TMY: Total milk yield per lactation (kg), DMY: Daily milk yield (kg), PC: persistence coefficient (%).

Milk fat and protein yield

Data about milk fat and protein evaluated during the entire lactation period are reported in **Table 3**. The average TFY per animal was 219.72 ±95.05 g. Furthermore, the average MFR over the entire lactation period was 1.94 ±1.13 %, and the average BY produced per animal amounted to 186.31 ±34.60 g. The overall average TPY per animal was 745.28 ±88.68 g, and the average milk protein rate content over the entire lactation period stood at 4.11 ±1.67 %.

Table 3. Milk fat rate per control, fat rate between the last control and the dry off of Arbia dairy goats breed

	N	Mean	SD	Min	Max
TFY (g)	66	219.72	95.05	152.04	434.78
MFR (%)	66	1.94	1.13	1.00	6.39
BY (g)	66	186.31	34.60	130	370
TPY (g)	66	745.28	88.68	495.07	926.34
MPR (%)	66	4.11	1.67	2.14	11.8

FR: Fat rate (%), TFY: Total fat yield per lactation (g), MFR: Milk fat rate per lactation (%), BY: Butter yield (kg), PR: Protein rate (%), TPY: Total protein yield (g), MPR: Milk protein rate per lactation (%).

The average MFR and MPR per control exhibited significant variations ($P < 0.01$). The highest average fat rate level (4.61 ±1.38 %) was recorded during the 5th control at 141.59 days post kidding, and the lowest (2.28 ±1.07 %) was observed during the last control (8th), averaging 229.18 days (**Figure 5**). On the other hand, the rate of the protein content displayed a range from 2.62 % to 4.73 %, with the highest levels recorded during the first control at 22.47 days (4.73 ±1.87 %, ranging from 2.96 % to 7.82 %), while the lowest levels were observed during the 8th control (2.62 ±0.91 %) (**Figure 5**).

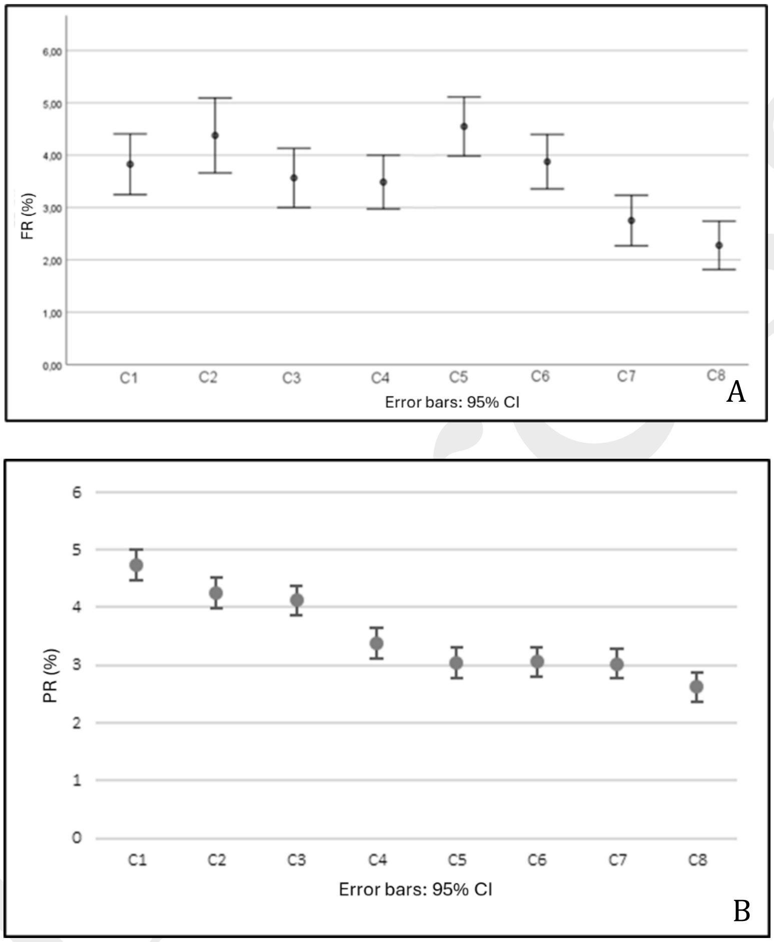

Figure 5. A) Average milk fat rate FR and B) protein rate PR per control along the lactation of Arbia goat (n = 66).

Correlation between lactation traits

The results of correlation analysis between variables related to lactation and milk production of Arbia goats are provided in **Table 4**. The DIM showed a strong positive correlation with TMY and KI. The TMY was negatively correlated with TFY and MFR.

Additionally, TFY is positively correlated with BY. For the protein yield, TPY showed a moderate positive correlation with DIM, MPR TFY. The PC showed very weak correlations with other variables.

Table 4. Correlations between lactation parameters of Arbia dairy goats

	DIM	TMY	DMY	KI	TFY	MFR	BY	PC	TPY	MPY
DIM	1.00									
TMY	0.871**	1.00								
DMY	0.10	0.561**	1.00							
KI	0.977**	0.887**	0.17	1.00						
TFY	-0.775**	-0.749**	-0.292*	-0.784**	1.00					
MFR	-0.709**	-0.789**	-0.525**	-0.723**	0.917**	1.00				
BY	-0.889**	-0.846**	-0.274*	-0.910**	0.960**	0.895**	1.00			
PC	0.03	0.16	0.302*	-0.01	0.04	-0.05	0.02	1.00		
TPY	0.826**	0.28	-0.16	0.399*	0.17	-0.03	0.20	0.30	1.00	
MPR	0.12	-0.868**	-0.939**	-0.29	-0.16	0.483**	-0.16	-0.19	0.17	1.00

DIM: Days in milk (days), TMY: Total milk yield per lactation (kg), DMY: Daily milk yield (kg), TFY: Total fat yield per lactation (kg), MFR: Milk fat rate per lactation (%), BY: Butter yield (kg), TPY: Total protein yield (kg), MPR: Milk Protein rate (%), PC: Persistence coefficient (%), KI: Kidding interval (days). Significance levels: * P < 0.05, ** P < 0.01, and *** P < 0.001.

Comparison of lactation traits according to the origin and lactation number

Animal's origin

The comparison of lactation parameters among the two study areas, Souk Ahras (SA) and Biskra (B), is reported in **Table 5**. The average DIM and the KI were significantly ($P < 0.001$) higher for animals from Biskra region compared to those from Souk Ahras region (DIM: 252.12 ±21.33 vs. 136 ±17.74 days and KI: 316.94 ±12.67 vs. 180 ±26.85 days). Conversely, the TFY, MFR ($P < 0.001$), and MPR ($P = 0.03$) were significantly higher in Souk Ahras than in Biskra. No significant difference was observed in TMY, DMY, TPY, and PC between the two regions ($P > 0.05$). Therefore, does from Souk Ahras exhibited higher total fat yield (TFY) and a comparable total protein yield (TPY) relative to those from Biskra, despite presenting a lower total milk yield and a shorter lactation length. This situation reflects the significantly higher levels of fat and protein content (MFR and MPR) in Souk Ahras compared to Biskra.

Lactation number

Table 6 presents a comparison of lactation parameters across different lactation orders, categorized from the 1st to the 5th lactation. The DIM, TMY, DMY, TFY, and KI tend to decrease as the lactation order increases ($P > 0.05$), showing a potential decrease in milk production and lactation performance in later lactations. The MPR appears to slightly increase with lactation order ($P > 0.05$), with the highest rate observed in the 4th lactation, while PC remains relatively consistent across different lactation orders.

Table 5. Comparison of lactation parameters between Souk Ahras and Biskra regions for Algerian local Arbia goats

	Region	N	Mean	SEM	Sig
DIM (days)	SA	32	136.00	3.56	***
	B	34	252.12	3.65	
TMY (kg)	SA	32	138.79	5.05	ns
	B	34	271.55	7.78	
DMY (kg)	SA	32	1.0200	0.03	ns
	B	34	1.0800	0.03	
KI (days)	SA	32	180.00	1.78	***
	B	34	316.94	2.17	
TFY (gr)	SA	32	260.35	13.81	***
	B	34	109.66	4.59	
MFR (%)	SA	32	2.0500	0.19	***
	B	34	1.4100	0.01	
PC (%)	SA	32	72.930	0.74	ns
	B	34	72.900	0.70	
TPY (gr)	SA	32	707.81	14.63	ns
	B	34	780.55	13.98	
MPR (%)	SA	32	5.430	0.26	*
	B	34	2.960	0.10	

SA: Souk Ahras region, B: Biskra region, DIM: Days in milk (days), TMY: Total milk yield per lactation (kg), DMY: Daily milk yield (kg), TFY: Total fat yield per lactation (kg), MFR: Milk fat rate per lactation (%), TPY: Total protein yield (kg), MPR: Milk protein rate (%), PC: Persistence coefficient (%), KI: Kidding interval (days). Significance levels: *P < 0.05, **P < 0.01, and ***P < 0.001.

Table 6. Comparison of lactation parameters according to the lactation number of local Arbia goats

	1st (n = 11)		2nd (n = 24)		3rd (n = 18)		4th (n = 9)		5th (= 4)		Sig
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	
DIM (days)	215.45	6.08	196.96	14.66	196.33	6.75	174	14.46	136	19.85	ns
TMY (kg)	218.37	11.65	207.06	23.25	214.91	8.28	192.1	18.30	84	30.03	ns
DMY (kg)	1	0.04	1.05	0.07	1.08	0.05	1.1	0.05	0.62	0.07	ns
TFY (g)	151.42	10.93	174.35	21.02	189.59	10.34	214.69	27.08	341.94	8.55	ns
MFR (%)	0.94	0.04	1.16	0.22	1.2	0.04	1.39	0.37	4.07	0.06	ns
PC (%)	72.42	0.84	72.4	1.35	74.17	1.58	72.6	0.91	72.37	2.23	ns
TPY (g)	765.46	22.84	729.30	20.15	746.20	33.41	761.89	27.93	788.61	69.12	ns
MPR (%)	3.87	0.14	4.03	0.37	3.96	0.14	4.41	0.52	4.38	0.03	ns
KI (days)	265	3.37	252.78	17.07	254.44	5.81	226.22	16.55	188	4.16	ns

DIM: Days in milk (days), TMY: Total milk yield per lactation (kg), DMY: Daily milk yield (kg), TFY: Total fat yield per lactation (kg), MFR: Milk fat rate per lactation (%), TPY: Total protein yield (kg), MPR: Milk protein rate (%), PC: Persistence coefficient (%), KI: Kidding interval (days).

Multivariate analysis of Total Milk Yield, Total Fat Yield and Total Protein Yield

The statistical models significantly predicted TMY, TFY, and TPY (R2 adjusted = 0.44-0.75, P < 0.001; **Tables 7–9**). However, only lactation length showed a potential influence on TMY, albeit at a borderline significance level (P = 0.07). Other factors such as age, lactation number, and animals’ origin do not appear to significantly affect TMY. None of the independent variables had a statistically significant impact on TFY. Conversely, two predictors emerged as significant determinants: animals’ origin and lactation length on TPY. The animals’ origin notably influenced the TPY (P = 0.01), with the negative coefficient suggesting a significant decrease in animals from Souk Ahras compared to Biskra (reference level). Additionally, lactation length significantly affected the TPY ($P < 0.001$), with longer lactation periods associated with higher protein outcomes, as indicated by the positive coefficient.

Table 7. Multivariable linear regression analysis of total milk yield in Arbia dairy goats

Factors	Estimate	SE	t	P-value	95 % CI
Constant	-13.26	30.94	-0.43	0.67	-75.14–48.61
Age	9.53	24.86	0.38	0.70	-40.19–59.25
Lactation number	-2.85	12.89	-0.22	0.83	-28.62–22.93
Animals’ origin	59.28	49.60	1.20	0.24	-39.89–158.45
Lactation length (days)	0.61	0.33	1.86	0.07	-0.05–1.26

Multivariable regression: age, lactation number, animals’ origin, and lactation length.

Model statistics: R^2 adjusted = 0.75, F = 54.77, $P < 0.001$.

Values are regression coefficients ±standard errors (SE). The least squares method was used. "Animals’ origin" reflects the farm location. Dependent variable: Total milk yield (TMY, kg).

Table 8. Multivariable linear regression analysis of total fat yield in Arbia dairy goats

Factors	Estimate	SE	t	P-value	95 % CI
Constant	373.73	47.68	7.84	0.00	278.39469.08
Age	-1.86	38.32	-0.05	0.96	-78.47–74.76
Lactation number	5.88	19.86	0.30	0.77	-33.84–45.59
Animals' origin	-128.88	76.43	-1.69	0.10	-281.71–23.95
Lactation length (days)	-0.08	0.51	-0.15	0.88	-1.09–0.93

Multivariable regression: age, lactation number, animals' origin, and lactation length.

Model statistics: $R^2 = 0.64$, R^2 adjusted = 0.62, F = 27.91, P < 0.001.

Values are regression coefficients ±SE. TFY expressed in grams. Dependent variable: Total fat yield.

Table 9: Multivariable linear regression analysis of total protein yield in Arbia dairy goats

Factors	Estimate	SE	t	P-value	95 % CI
Constant	504.73	54.34	9.29	0.00	396.08–613.38
Age	-16.61	43.66	-0.38	0.70	-103.92–70.69
Lactation number	15.84	22.63	0.70	0.49	-29.41–61.10
Animals' origin	-251.43	87.09	-2.89	0.01	-425.59–77.28
Lactation length (days)	3.05	0.58	5.30	0.00	1.90–4.20

Multivariable regression: age, lactation number, animals' origin, and lactation length.

Model statistics: $R^2 = 0.48$, R^2 adjusted = 0.44, F = 14.13, P < 0.001.

Values are regression coefficients ± S.E. TPY expressed in grams. "Animals' origin" was initially included but found collinear with breeding system (r = 1) and was therefore excluded from final models to avoid multicollinearity.

Typology of goat production performances

Linear correlations between lactation traits of dairy goats and the first three Principal Components (PCs) are presented in **Table 10** and **Figure 6**. The PCA results reveal the contribution of variables to the first three axes. Together, these three factors capture 83.6 % of the information contained in the lactation data. The first principal axis (PC1) explains 61.37 % of this total information. The variables DIM, TDY, KI, TFY, MFR, BY, and MPR significantly contribute to this first factor. The second principal axis (PC2), representing 12.22 % of the variance, is primarily influenced by the variables PC and TPY. Finally, the third principal component (PC3) explains 10 % of the variance and is mainly characterized by the variable DMY.

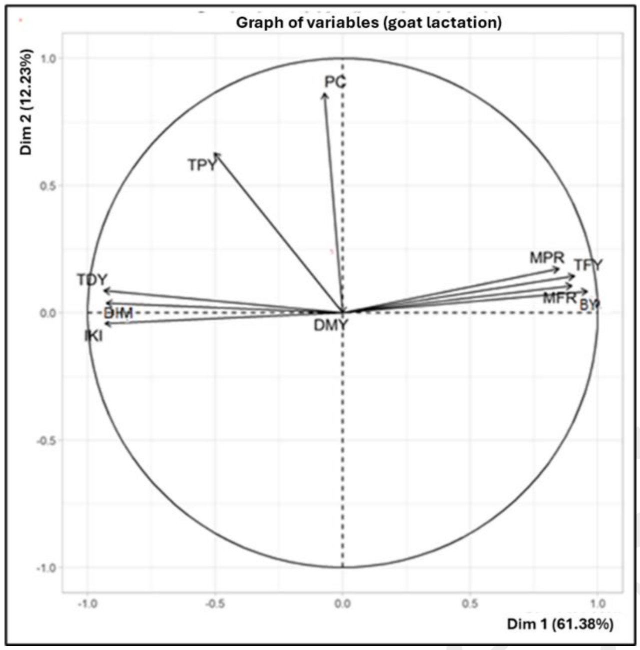

Figure 6. Pearson's correlations between the first two principal components (PCs) and lactation traits.

The categories "Biskra" and "Souk Ahras" of the qualitative variable "origin of the animals" are positioned to the left and right of PC1, respectively. From these observations, we can conclude that axis 1 corresponds more to the assessment of the quantity and quality of milk produced by goats, while axis 2 corresponds mainly to the evaluation of lactation persistence, and axis 3 to the evaluation of the average daily milk production. **Figure 7** illustrates the distance between individuals according to the illustrative variable (origin). Animals from the Biskra region are perfectly separated from those from the Souk Ahras region (**Figure 7**).

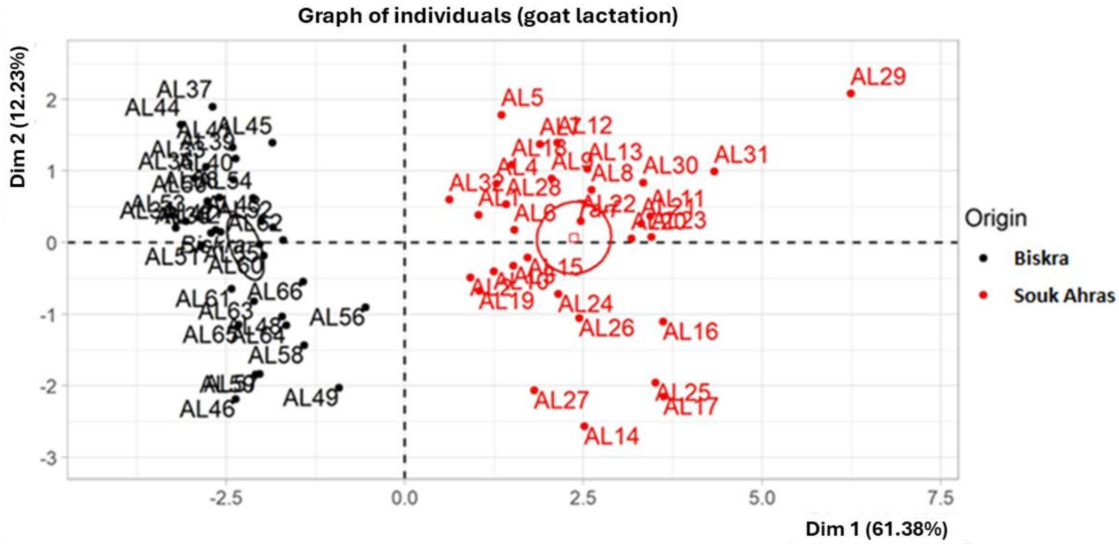

Figure 7. Distance between individuals based on the qualitative variable (origin) according to PC1 and PC2 of the PCA.

Furthermore, when utilizing production traits to elucidate potential effects on the principal component loadings, a distinct clustering of observations was discerned within the first two PCs. An overlapped stratification was noted concerning DIM, TDY, and TFY (**Figure 8**), with animals from the Souk Ahras region exhibiting shorter lactation lengths, reduced total milk yield, and elevated total fat yield per lactation.

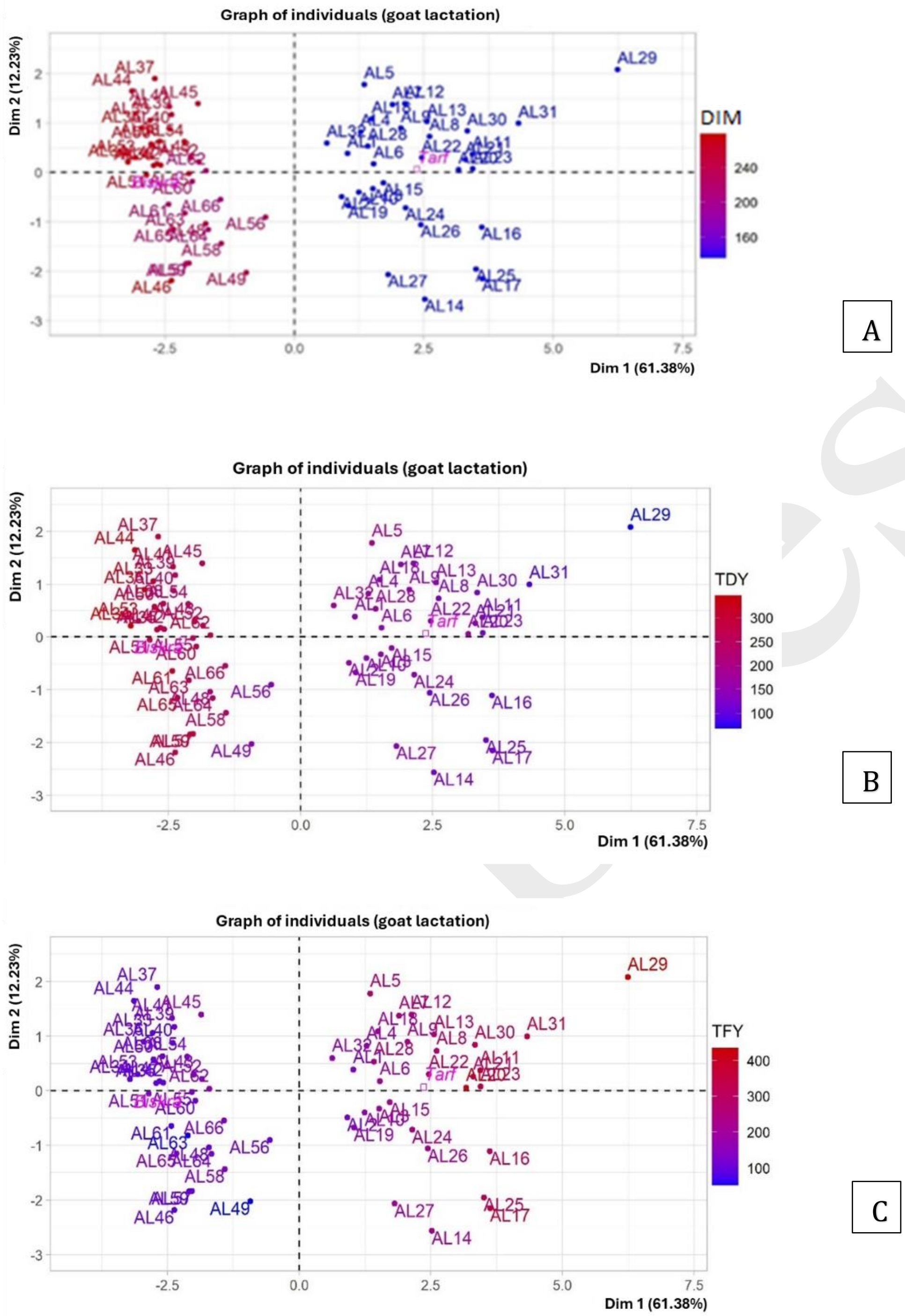

Figure 8. Distribution of individuals based on production traits Days in milk (DIM), Total milk yield per lactation (TDY) and Total Fat Yield (TFY) according to PC1 and PC2 of the PCA.

We distinguished 03 animal groups according to their lactation performance figures, as shown in **Tables 11–13** and **Figure 9**.

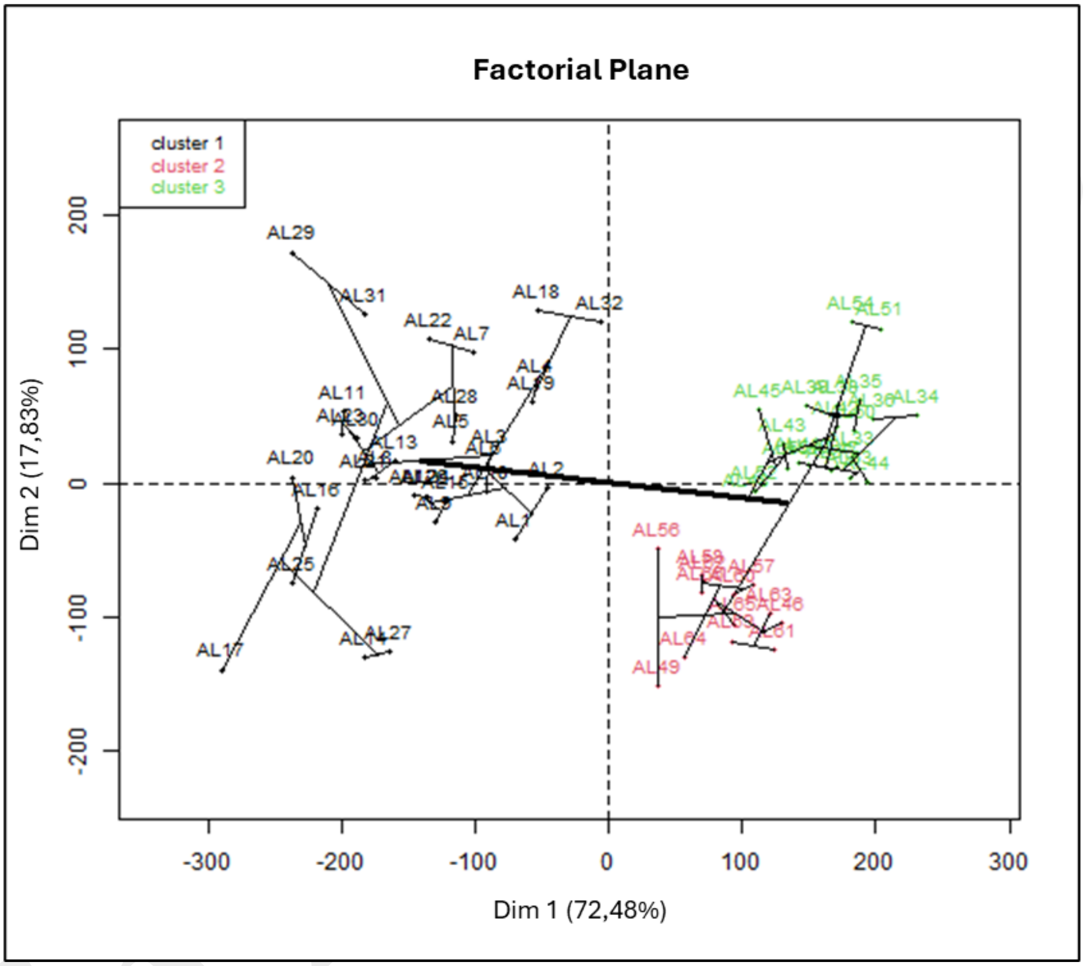

Figure 9. Clustering of individuals generated by hierarchical ascending classification (HAC), with the PCs as independent variables.

Table 10. Contribution of goat lactation traits to the construction of the first three principal components

	Dim.1	Dim.2	Dim/3
DIM	14.01	0.12	0.00
TDY	14.28	0.62	0.00
DMY	0.00	0.00	100/0
KI	14.15	0.15	0.00
TFY	13.45	1.72	0.00
MFR	13.16	0.93	0.00
BY	15.01	0.58	0.00
PC	0.08	61.07	0.00
TPY	4.12	32.35	0.00
MPR	11.73	2.47	0.00

Cumulative variance = 83.6 %

DIM: Days in milk (days), TDY: Total milk yield per lactation (kg), DMY: Daily milk yield (kg), KI: Kidding interval (day) TFY: Total fat yield per lactation (kg), MFR: Milk fat rate per lactation (%), BY: Butter yield (kg), TPY: Total protein yield (kg), MPR: Milk Protein rate (%), PC: Persistence coefficient (%).

Table 11. Characterization by continuous variables of the first class of the partition

	Mean in category	Overall mean	SD in category	Overall SD	v.test	P-value
KI	316.94	250.54	12.49	69.02	7.99	0.000
DIM	252.11	195.81	21.01	59.96	7.80	0.000
TMY	271.54	207.18	44.72	76.27	7.01	0.000
TPY	780.55	745.28	80.32	88.68	3.31	0.000
MPR	2.96	4.11	0.62	1.67	-5.74	0.000
MFR	1.41	1.94	0.11	1.12	-5.87	0.000
TFY	109.66	219.72	26.36	95.05	-6.44	0.000

Cluster 1 / 3: n = 34. 51.51 %

DIM: Days in milk (days), TMY: Total milk yield per lactation (kg), KI: Inter-calving interval (days) TFY: Total Fat yield per lactation (g), MFR: Milk fat rate per lactation (%), TPY: Total protein yield (g), MPR: Milk protein rate (%).

Table 12. Characterization by continuous variables of the second class of the partition x

	Mean in category	Overall mean	SD in category	Overall SD	v.test	P-value
DMY	1.15	1.05	0.11	0.19	2.76	0.003
TFY	226.54	182.72	66.36	94.32	2.47	0.007
TMY	156.97	207.18	15.38	76.27	-3.50	0.000
DIM	136.00	195.81	0.00	59.96	-5.30	0.000
KI	180.00	250.54	0.00	69.02	-5.43	0.000

Cluster 2 / 3: n = 20. 30.30 %

DIM: Days in milk (days), TMY: Total milk yield per lactation (kg), DMY: Daily milk yield (kg), KI: Kidding interval (days) TFY: Total fat yield per lactation (kg).

Table 13. Characterization by continuous variables of the third class of the partition

	Mean in category	Overall mean	SD in category	Overall SD	v.test	P-value
MFR	3.0700	1.2000	1.150	1.120	6.29	0.000
TFY	316.69	182.72	57.89	94.32	5.40	0.000
MPR	6.4400	4.1100	2.010	1.670	5.28	0.000
TPY	668.91	745.28	85.16	88.68	-3.27	0.001
DIM	136.00	195.81	0.000	59.96	-3.79	0.000
KI	180.00	250.54	0.000	69.02	-3.88	0.000
DMY	0.7900	1.0500	0.110	0.190	-4.88	0.000
TMY	108.49	207.18	15.900	76.27	-4.92	0.000

Cluster 3 / 3: n = 12. 18.18%

DIM: Days in milk (days), TMY: Total milk yield per lactation (kg), DMY: Daily milk yield (kg), KI: Inter-calving interval (days) TFY: Total fat yield per lactation (kg), MFR: Milk fat rate per lactation (%), TPY: Total protein yield (kg), MPR: Milk protein rate (%).

Cluster 1 (N = 34, 51.51 %): This class is characterized by high TMY with prolonged DIM and longer IK interval. 100 % of the animals in this class belong to the agroecological area of Biskra. They have an KI of 316.941 days, a DIM of 252.118 days, a TMY of 271.548 kg, and a TPY of 780.556 kg. Although their milk production is high, their lactation duration and inter-kidding interval are longer than the overall average.

Class 2 (N = 20, 30.30 %): This class represents animals from the Souk Ahras region. They are characterized by moderate but stable milk production. On average, these animals have a DMY (Daily milk production) of 1.155 kg, a TFY (Total fat yield) of

226.544 kg, a TMY of 156.974 kg, a DIM of 136 days, and an KI (Inter-kidding interval) of 180 days. These values are lower than the overall average, indicating lower but consistent milk production in this class.

Class 3 (N = 12, 18.18 %): This class is distinguished by high milk production characteristics but with shorter DIM and KI. Animals in this class are from the Souk Ahras region. They have an MFR of 3.071 %, a TFY of 316.693 kg, an MPR of 6.442 %, a TPY of 668.918 kg, a DIM of 136 days, and an KI of 180 days. Although their milk production is high, their lactation duration and inter-kidding interval are shorter than the overall average.

Discussion

Our study was conducted with regular lactation monitoring in Arbia, where cows are typically kidded during the spring season in two distinct agroecological areas. The average DIM and the mean duration of the dry period were 195.82 ± 60.42 and 54.73 ± 16.66 days, respectively. The average total milk yield per lactation was 207.18 ±76.86 kg, without a significant difference between milk quantity produced by goats from the Souk Ahras and the Biskra regions ($P > 0.05$). The DIM (170 days) and TMY (160 ±43 kg) reported by Djouza and Chehma[32] for Arbia goat breed from Biskra region in the arid Algerian zone were lower than those recorded in our study. Also, our results are higher than those reported by Moula et al. and Kouri et al.[3, 33] at the early lactation stage (13 weeks) of the Arbia goat breed reared at Algerian arid conditions.

The mean duration of the dry-off period was similar to that reported in Alpine, La Mancha, Nubian, Saanen, and Toggenburg does.[34] Comparing our results to the lactation performance of other goat breeds of arid and mountainous regions, the achieved total milk yield is considered satisfactory when juxtaposed with data provided by Kerbaa[35] for the "Makatia" goat breed in Algeria (80 kg within 120 days), Kabylian goats (557.5 ±1.2 mL/day), and other African goat breeds like Nigerian Red Sokoto goat,[36] Egyptian Zaraibi and Shami goats[37] and black Moroccan goat[38] and also to that for the Corsican breed in Corsica (150 kg within 150 days).[39]

Nonetheless, the TMY level seems to be much lower compared to the "Mozabite" goat (460 kg within 180 days) and the "Murciano-Granadina" (584 kg within 287 days), as assessed respectively by Kerbaa[35] in Algeria and by Delgado et al.[40] in Spain and even more significantly lower when contrasted with genetically improved breeds such as Alpine goat (800 kg of milk in 280 days) and the Saanen goat (900 kg in 280 days),[25, 39, 41] the goat under study exhibits considerable divergence from being categorized as a purely dairy breed. The comparison between breeds reveals a wide range of characteristics. This variation in lactation length, milk yield, and composition, and persistency, influenced by breed and management systems, poses challenges for comparing scientific studies and achieving industry standardization.[41]

The Arbia goat breed, despite its low production level compared to specialized breeds, holds significant interest due to its adaptability to local conditions (arid and semi-arid), resilience to diseases and environmental stresses, and contribution to genetic diversity.[13] They play a crucial role in preserving agrobiodiversity, offering sustainable solutions to future challenges such as climate change and representing a key element of cultural heritage; stimulating local economic development through sustainable production and the valorization of local products.[13] Furthermore, this breed could constitute an interesting model for the genetic improvement of its milk performance by involving selective breeding and crossbreeding programs. Examples of such improvement programs have led to a significant increase in milk production and profitability for local breeders of goat breeds such as the Jamunapari breed in India, West African Dwarf and Red Sokoto breeds in West Africa, the Toggenburg breed from Switzerland, and the Arsi breed in Ethiopia.[42–44]

Milk yield was affected by postpartum months of conception. The average lactation curve in the Arbia goat is characterized by a milk production peak of 1.77 ±0.50 kg/day reached at 89.22 ±10.76 days post-kidding. Mean PC of milk production per lactation ranged from 64.85 % to 82.22 %, averaging at 72.91 ±4.13 %. These results characterizing the lactation curve are similar to those reported by Djouza and Chehma[32] in the Arbia goat from the Biskra region, characterized by a lactation peak at the 12th week, reaching a daily maximum production of about 1.04 ±0.34 kg. Kouri et al.,[33] reported an earlier and lower peak of milk production: 0.71 ±0.09 kg at the 6th week post kidding in a similar experimental environment. The decreasing lactation phase was 70 days in the studied animals, which is comparable to that reported by Djouza and Chehma.[32]

The average of the DMY per animal was 1.05 ±0.20 kg, which is higher than that reported by Djouza and Chehma:[32] 0.89 ±0.91 kg and Kouri et al.[33] 0.56 ±0.06 kg. Previous reports in the Makatia Algerian goat breed found that milk production was about 1–2 L/day in Algeria,[45, 46] which was close to our results in the Arbia breed, which originates from different regions in Algeria. However, the studied animals produced higher milk quantity as compared to Draa goat (0.46 L/day) conducted in a permanent housing in Morocco.[28] Milk production in dairy goats is influenced by a multitude of factors, encompassing both intrinsic characteristics of the animals and external environmental conditions. Intrinsic factors include breed, body size, weight, age, and prolificacy, while environmental variables comprise temperature, kidding season, and management practices.[45, 33, 47, 48]

Low milk yield often stems from inadequate body condition due to energy and protein deficiencies in feed, notably prevalent in arid and semi-arid regions with limited rainfall.[33, 49] The timing of parturition can also impact milk production, with lactations commencing earlier in the year sometimes yielding lower volumes.[50, 51] Cold temperatures have been observed to diminish milk secretion in lactating goats, and local goat breeds were reported to better tolerate these environmental constraints compared to specialized high milk-yielding breeds.[52] The Same statement was reported for the production and reproduction of North cattle and sheep livestock under different agroecological conditions of North Africa.[53–55] Additionally, genetic factors play a pivotal role, with dairy breeds typically exhibiting higher milk production potential compared to mixed or meat breeds.[56]

In this regard, some morphological characteristics were observed to have significant correlation with milk traits in Arbia goat from the Algerian arid region, mainly withers height, rump height, udder width, and udder circumference.[33] Females delivering twins generally produce more milk than those with single births.[33, 57] Other influential factors include body size, weight, udder attachment, and development, along with age at first calving and the interval between parturition and mating.[58, 59] Furthermore, the overall health status of the animal significantly influences milk production, with subclinical diseases posing a greater threat than clinical ailments.[60–62] Therefore, maintaining optimal animal health is paramount for maximizing milk yield.[63]

The observed intervals for DO and KI in the study (**Table 1**) align closely with existing data for Boer goats maintained under favorable management conditions in various climatic regions, including arid, semi-arid, and humid zones. These intervals suggest good reproductive performance, reflecting the ability of does to achieve inter-kidding intervals of 7–8 months, produce up to four kids per parturition, and average litter sizes approaching two kids.[64] Similar reproductive metrics have been documented in other breeds as well, such as the Short-Eared Somali,[65] Ethiopian Central Highland,[66] and Arab breeds.[29, 67] Studies by Lehloenya et al.[64] and more recent summaries by Getaneh et al.[30] provide comparable findings, demonstrating consistency in reproductive performance across these different goat breeds and environmental conditions. The relatively high mean of days open and subsequently the kidding interval could be due to undetected estrus in herds using oriented mating or failure of does to return to estrus early after kidding because of the seasonality of breeding in goats.

The milk composition results in our study, particularly the significantly higher fat and protein levels in animals from Souk Ahras, suggest regional influences on milk quality. The significantly higher fat and protein content in the milk of goats from Souk Ahras underscores the impact of regional conditions on milk quality. However, these values were lower than those reported in previous studies on grazing goats,[68, 69] suggesting that grazing practices and environmental factors significantly influence milk composition. The differences might be due to variations in feeding practices, environmental conditions, and genetic factors. According to Djouza and Chehma,[32] Kouri et al.,[33] who investigated lactation performance of the Arbia goat breed in a similar arid region of our study area, the average goat milk composition of 3.5 % of fat, 3 % of protein,[32] and 3.49 % and 3.89 %[33] was reported.

Compared to our results, these authors indicated a similar MPR and a higher MFR. For this last parameter, our results are somewhat close to the reported levels in the Arbia breed at arid and semiarid regions.[32, 33, 70] The protein rate showed a high concentration in the first week of lactation, then dropped continuously. The pattern of MPR change was similar to that reported by Kouri et al.,[33] with the highest protein rate recorded in the first week (first control). Similarly, these authors recorded the highest MFR at the first control, conversely to our records, where we observed two MFR peaks in the 2^{nd} (56 days) and 5^{th} controls (141 days). The observed low MFR can be attributed to the tendency of goats, particularly those with lower production capabilities, to retain their milk during milking sessions. Additionally, the protein and fat rates decline during the subsequent lactation month of lactation is likely a result of dilution effects stemming from the increased milk yield during this period.

Compared to other local goat breeds, Amroun et al.[71] reported higher averages of MFR and MPR in Kabilyan Algerian goats from the montagnious region (MFR: 39.6 ±0.1 % and MPR: 48.9 ±0.2 %). Intrinsic factors like genetics and lactation stage, as well as extrinsic factors including diet and environment, influence milk composition. The milk fat and protein rates would be particularly high during periods of food restriction and thermal and hydric stress, due to farming conditions (natural grazing, Mediterranean climate), and forage quality (dry matter content).[71] According to Flores-Najera et al.,[72] milk fat content was influenced by temperature, precipitation, kid sex, and offspring weight gain, while protein content showed no significant variations across different factors.

The highest average MFR (4.61 ±1.38 %) was recorded during the 5th control at 141.59 days post kidding, while the lowest (2.28 ±1.07 %) was observed during the last control (8th) at 229.18 days. Conversely, the rate of protein content ranged from 2.62 % to 3.39 %, with the highest levels recorded during the first control at 22.47 days (3.39 ±0.40 %), and the lowest levels observed during the 8th control (2.62 ±0.91 %). DIM and IKI showed a strong positive correlation with TMY. These positive correlations do not necessarily imply that breeding after kidding should be delayed.(34) Regression analysis suggests a quadratic relationship between reproduction and lactation traits.(34)

Furthermore, TMY was negatively correlated with TFY and weakly correlated with TPY. A negative relationship between milk quantity and quality was established previously.(23, 68) The milk composition may differ in grazing goats despite their milk-yielding potential.(69) These findings underscore the importance of factors such as lactation management, feeding practices, and goat health in optimizing milk production and milk quality. The factors influencing total protein yield may be multifaceted and not solely dependent on lactation length or other measured variables. PC shows very weak correlations with other variables, suggesting that its relationship with lactation length, milk yield, or other factors may be minimal. This could imply that factors influencing milk persistency may be independent or have weaker associations with other variables measured in the study.

These findings highlight the complexity of factors influencing milk production and composition in goats. While DIM and TMY play important roles, other factors such as PC, TPY, and MPR, also contribute to understanding milk production dynamics and quality. Our findings suggest that lactation performance, as indicated by parameters such as DIM and TMY, tends to decrease with higher lactation orders (parity), while MPR and PC show more variable patterns across lactation orders. According to Ciappesoni et al.,[73] the milk yield increased progressively with the parity until the 3rd lactation. Zamuner et al.[51] reported that the maximum milk yield was attained in the third parity, and the lowest proportion of does reaching DIM of 270 days was observed from the 4th parity.

Margetín[74] recommended the following correction coefficients for milk production of goats on different lactations: 1st lactation 1.40; 2nd lactation 1.12; 3rd and further lactations 1.00. The DIM tends to be the shortest in advanced parity. The differences in these results may be related to several factors: physiological changes in mammary gland tissue, age-related metabolic decline, nutritional demands, reproductive factors, genetic limitations, and management practices. The mammary gland tissue changes with age, potentially affecting milk production capacity, while cumulative effects of multiple pregnancies and lactations may influence subsequent lactation performance. Age-related metabolic changes and differing nutritional requirements for higher parity animals may also impact overall productivity.

Additionally, inherent genetic potential for milk production may be expressed differently across parities, and variations in care and management for animals of different ages may contribute to parity effects. Understanding these parity-related patterns is crucial for optimizing herd management and breeding strategies in Arbia goats. The typology of the studied animals using PCA based on test days lactation characteristics reveals three distinct profiles: moderate but stable milk production, high milk production with shorter lactation duration and kidding intervals, and high milk production with extended lactation duration and longer kidding intervals. Recent research has demonstrated the potential benefits of extended lactation compared to standard lactation in dairy goat farming.

The extended lactation could be a viable management strategy, offering comparable or slightly better milk production while simultaneously improving goat longevity and lifetime efficiency.(75) This approach shows promise for enhancing overall farm productivity without compromising milk yield, suggesting a potential shift in traditional dairy goat management practices.(75) The diversity of Arbia dairy goats generated using factorial analysis is mainly due to high variance in the overall level of milk production and the length of the DIM period, kidding interval, and milk quality. These parameters, along with the persistence coefficient, were identified as the main factors of genetic diversity among dairy goats in France.(25) Lactation persistency, which plays a key role in discriminating lactation curve types, highlights a certain variability.

Conclusions

Our research sheds light on lactation performance and milk production dynamics in Arbia goats, underscoring the breed's significance in local agriculture, biodiversity conservation, and genetic enhancement initiatives. The findings emphasize the Arbia breed's substantial potential to consistently yield milk of notably different quantitative and nutritional qualities, particularly according to animals living agroecological area and the lactation length period. Arbia dairy from arid regions exhibits prolonged lactation periods and extended inter-kidding intervals. In semi-arid areas, two distinct production profiles emerge: moderate yet consistent milk production or high production levels with shorter lactation length and inter-kidding intervals. This diversity in milk production among Arbia goats prompts consideration of tailored strategies aimed at optimizing their performance, leveraging their unique ethnozootechnical characteristics and environmental adaptations.

Data availability

All relevant data are within the manuscript and its supporting information files.

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Conflicts of interest

The authors have no conflict of interest to declare concerning this publication.

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