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REGULAR ARTICLES

Lactation traits and reproductive performances of Sahraoui female camel in two breeding systems at Algerian Sahara

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Abstract

The main objective of this study is to determine the impact of the camel livestock system on individual and herd performances of milk production, lactation curve, fats, and protein concentrations. For this purpose, 13 she-camels of Sahraoui breed from the south eastern Algeria and belonging and semi-intensive system ($N = 6$) and intensive system ($N = 7$) were studied. Recording and sampling of milk were carried out at regular intervals during a full lactation. The lactation curve was estimated using Wood's gamma function and the *t*-test of independent groups was carried out to compare lactation performances, lactation curve, and reproductive parameters. The overall average daily milk (DMY), fat (DFY), and protein (DPY) yield were 6.77 ± 0.82 kg/day, 4.15 ± 0.91%, and 4.49 ± 0.20%, respectively. The mean of total milk yield (TMY) was 2696.39 ± 343.86 kg during a mean lactation length (LL) of 398.38 ± 20.65 days. The peak of milk production (6.79 ± 0.68 kg) was reached at 93.9 ± 55.8 days after calving. The open day (DO) and inter-calving interval (ICI) recorded in this study were 348.38 ± 30.33 and 723.38 ± 30.33 days, respectively. There is no significant difference ($p > 0.05$) between intensive and semi-intensive breeding systems for TMY (2795.39 ± 261.88 kg vs. 2580.89 ± 414.43 kg), DMY (6.96 ± 0.66 kg vs. 6.55 ± 1.00 kg), and LL (402.14 ± 21.18 days vs. 394 ± 21.03 days). However, the total amount of fat was significantly higher in intensive system (182.02 ± 33.91 kg) and the DPY content was significantly higher in semi-intensive system (4.60 ± 0.13%). The parameters α, β, and γ of lactation, fat, and protein curves between the two systems showed a highly significant difference ($p < 0.01$) for the parameters (α and β) for the milk production curve, significant ($p < 0.05$) for the time to reach peak yield, and no significance for the other parameters. The corresponding values of the coefficient of determination (R^2) were 0.62, 0.35 for milk yield ($p > 0.05$), 0.12, 0.13 ($p > 0.05$) for fat, and 0.03, 0.11 ($p < 0.05$) for protein, in the intensive and semi-intensive systems, respectively. In addition, DO and ICI were not significantly different between the livestock systems, but were higher in the intensive system than the semi-intensive system (337.17 ± 26.26 vs. 712.17 ± 26.26, respectively). The study concluded that the intensive system had a higher milk performance with a more efficient lactation curve. The incomplete gamma model (Wood) used in this study was inappropriate for estimating milk yield, but acceptable for fat and protein.

Keywords Dairy camel · Lactation curve · Livestock system · Milk composition

Introduction

Due to their unique physiology and in light of the current climate change impacts on ecosystems, camels are poised to be an excellent candidate species for production (Hoffmann 2010; Faraz et al., 2019). This is specifically true in regions where agro-pastoralism is being replaced by pastoralism due to climate change (Bornstein and Younan 2013; Faraz 2020). The commercialization of camel milk has seen a remarkable development.

This is mainly due to the increasing demand for camel milk due to its dietary and therapeutic benefits for treating some chronic diseases such as autism (Shabo and Yagil 2005; Akbar et al., 2020), diabetes (Agrawal et al., 2007, Hussain et al., 2021), anemia, and its anti-cancer (Magjeed 2005) and anti-hypertensive properties (Quan et al., 2008). It is also recommended for children allergic to lactose in cow's milk (El-Agamy et al., 2009), and includes lactoferrin proteins, IGg, lactoperoxidases, lysozymes, and peptides with antibacterial

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properties (El-Agamy et al., 1992; Konuspayeva et al., 2004), such as lactoferrin, IGg, lactoperoxidase, lysozyme, and peptides (Barbour et al., 1984; Duhaiman 1988). Compared to other livestock animal species, camels are better adapted to arid conditions and valorize better the forage resources in these regions by producing more milk with a longer lactation (Farah et al., 2007; Faraz 2020). Three camel husbandry systems have been identified in the Southeast of Algeria: nomadic, sedentary, and semi-sedentary (Gherissi and Gaouar 2022a,b; Harek et al., 2022; Chergui et al., 2023).

In Algeria, there is a lack of official control of livestock animals' lactation performances. Very few studies have been conducted to evaluate the milk potential of camel species. To date, the available data comes from surveys and field observations (Chehma 2003; Adamou and Boudjenah, 2012). No study has been conducted on the entire lactation of camels, taking into account the evaluation of the genetic potential of this animal through standard milk performance control, the analysis of the lactation curve profile, and the comparison of these data between existing livestock systems. This type of investigation is mandatory for the improvement of the local population's genetic potential (Gherissi and Lamraoui 2022). In this regard, the heritability estimates for milk yield at 305 days and test day yields were 0.24 and 0.22 (Almutairi et al., 2010; Gherissi et al., 2021), showing that the respective traits can indeed be improved through selection. In addition to genetic factors, milk production varies by region and depends on extrinsic factors such as the livestock system, breed, diet, climatic conditions, and intrinsic factors such as lactation rank, lactation stage, milking frequency, and the presence of the camel calf (Chehma 2003; Meribai et al., 2016).

Furthermore, the simple search of genetic improvement of milk production in camel breeding should not be separated from the question of sustainable development of livestock systems and their evolution (Gherissi et al., 2021). Currently, we are increasingly seeing the accentuation of environmental aridity linked to climate change, the globalization of the economy pushing camel breeding to be more integrated into the market, the modification of the territorial distribution marked by an expansion of the area of camel breeding, and an increasing risk of emerging diseases (Faye and Konuspayeva, 2012; Babelhadj et al., 2018). This undoubtedly implies a multidisciplinary approach to move forward and improve this sector.

The incomplete gamma function or Wood's function is particularly effective for fitting the observed daily milk production (Rekik et al., 2003). Understanding the parameters of the lactation curve can predict total production from a single control (test-day) and help to compare and evaluate the milk production potential of different breeds or animals. This information helps to make informed decisions regarding breeding and selection for optimal milk production (Wood, 1974). Overall, the use of mathematical models to analyze lactation curves is essential for successful dairy herd management and genetic evaluation. By examining milk, fat, and protein curves, dairy producers can make informed decisions about their herds and improve overall milk production.

This study aims to assess the lactation and reproductive performances of Sahraoui camels in two different livestock systems (semi-intensive and semi-extensive). It constitutes a first attempt at the national scale. Our study therefore consists of an evaluation of the milk quantity and quality in this species with an adjustment of the lactation curve and an analysis of the impact of management systems on the main parameters of the milk production curve, fat, and protein.

Materials and methods

Study area

The study was conducted in the El Oued region of southeastern Algeria. This region is characterized by an arid climate. Camel breeding is a capital-intensive livestock activity and a multi-purpose species in the study region. The privilege of this region is related to the accessibility to information and the breeding of camels as a dairy animal. Data from two herds were used in this study.

Animals and camel farms

This study involved the participation of 13 lactating dromedary camels. They were categorized into two systems: intensive and semi-intensive. The studied animals belonged to the Sahraoui breed, known for its excellent adaptation to the challenging conditions of the northern Algerian Sahara, one of the most arid regions in the world. This breed is prevalent, prominent, and highly traded in the study area. The Sahraoui population is highly regarded as a versatile working animal, valued for both meat and wool production. Additionally, some females exhibit exceptional milk production capabilities (Chergui et al., 2023). The average age of the studied animals was 11.23 ± 4.15 years, and the number of lactations varies from 1 to 8. Although the animals remained in good health throughout our study period, we administered an anthelmintic (fenbendazole: Fencur®) prior to the study. It is noteworthy that in two farms, the welfare of the camels was diligently maintained, as highlighted by Masebo et al. (2023).

A partnership was formed with the private dairy farm "TIDJANE SOUF," which practice the semi-intensive camel breeding system. Seven Sahraoui female camels from this farm were selected for inclusion in the study (Fig. 1). The farm is located in the commune of MAGURAN (33°33′44″N, 6°55′49″E), 25 km from El OUED. The animals primarily rely on foraging in Saharan rangelands in the mornings, following milking and water consumption. In the evenings, they are supplemented with

Fig. 1 Sahraoui she-camel in a semi-intensive system

Fig. 2 Sahraoui she-camel in an intensive system

concentrated feed, typically purchased wheat bran (2 kg/day/animal) with barley subsidized by the state (1 kg/day/animal), after returning from grazing (immediately after milking, the camels are released into the neighboring desert pastures (from 8 am to 17 pm)). The most common desert plant families in this region are as follows: *Chenopodiaceae*, *Plumbaginaceae*, *Poaceae*, *Chenopodiaceae*. Additionally, the camel calves are separated from their mothers each evening. These animals are accommodated in open-air enclosures, as illustrated in Fig. 1. Milking is carried out manually once a day by two skilled camel-milkers, while a shepherd oversees the herd's management. The collected milk is used for various purposes, including the production of pasteurized milk, fermented milk, camel cheese, and other camel milk-based byproducts, such as soap. Milk production data were collected from six female camels throughout an entire lactation period.

On the other hand, we also closely monitored seven female Sahraoui camels from an intensive camel breeding farm located approximately 5 km from El Oued (Fig. 2). Their milk production was meticulously observed and recorded. These camels were provided with a diet primarily composed of palm by-products (ad libitum), date palm rejects (4 kg/day/animal), wheat bran (2 kg/day/animal), straws (wheat and peanut) (3 kg/day/animal), and alfalfa hay (1 kg/day/animal). All these components were fed in two separate meals per day (before each milking process). A mixture of wheat bran and date residues was given, whereas straws were provided to the animals immediately after milking. The animals enjoyed unrestricted access to drinking water. These female camels were housed in open-air enclosures, and the calves were typically separated from their mothers for the majority of the day, except during milking times (Fig. 2). Milking was performed manually twice a day, scheduled at 6:00 AM and 5:00 PM, with the owner personally overseeing the milking process and herd management.

Milking procedure

Given the elevated udder position of the she-camel, the milking process is performed manually in a standing position (Fig. 3). The milker holds a plastic bucket in one hand and performs milking with the other hand. Prior to milking, the milker takes care to properly secure the camel by tying a rope to one of the animal's front legs. The milking process begins after thoroughly cleaning the udder with a damp cloth. To stimulate milk ejection (Fig. 4), the milker allows the calf to suckle for a maximum of 10 s before commencing the milk extraction.

Collection data and laboratory analysis

During our initial visit to both farms, she-camels were identified and selected. We chose females that were no more than 1 month old from their calving, which occurred between December 2021 and February 2022. The first control session

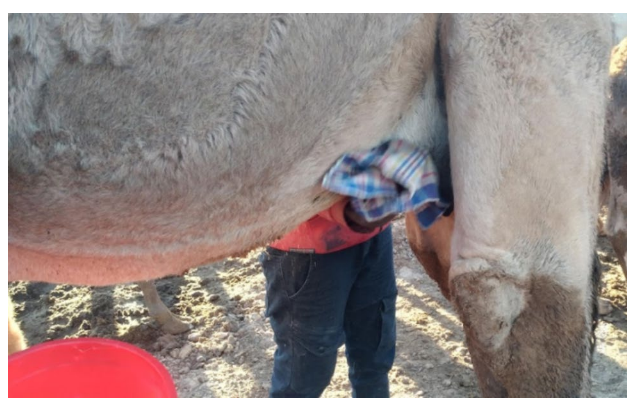

Fig. 3 Cleaning the udder with a damp cloth during the pre-milking time

Fig. 4 Manual milking, in the presence of the camel calf

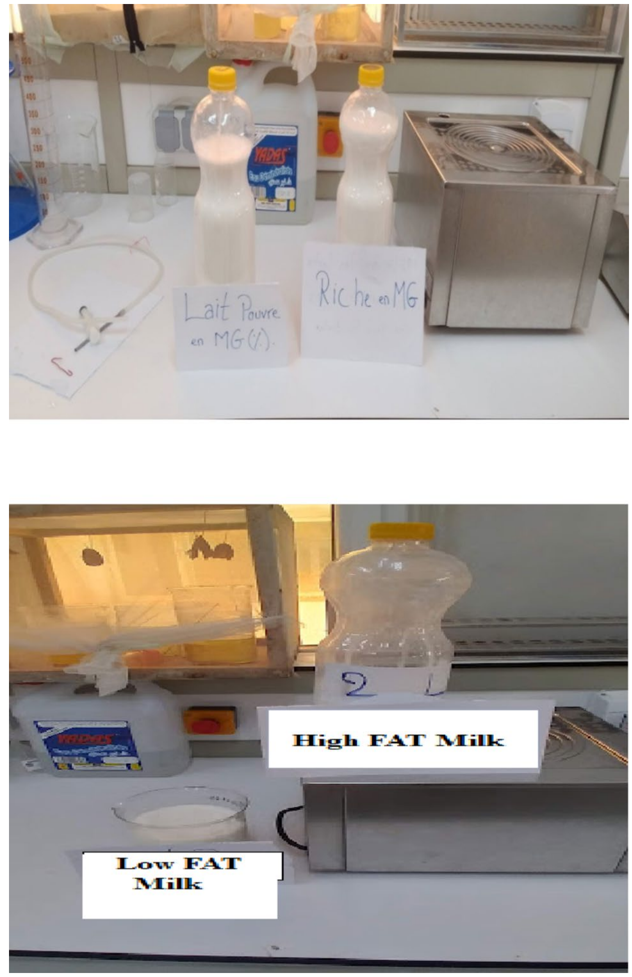

Fig. 5 Preparation of the two milks from the region (rich and poor in fat) for recalibration of Lactoscan SAP50

took place on February 5, 2022, and milk production was measured at regular intervals. This initial control happened within a range of 5 to 38 days for all the camels under study. Subsequent controls were conducted at consistent intervals of 26 to 33 days during the first 12 months of lactation.

To facilitate milk let-down, the camel calves were separated from their mothers for 13 h before each milking session. During milking, the young camels were allowed to suckle at the time of milking to stimulate milk release from only two quarters: one anterior and one posterior on the same side. The remaining quarters were emptied into a bucket, and the milk was then weighed using an electronic scale with a precision of 1 g. To calculate the total daily milk production of each camel, we applied the formula established by Hammadi (1996) and considered in Kadri (2021) to evaluate quantitative and qualitative milk production in camels. The formula of Hammadi (1996) is based on the quantity of milk obtained during milking (Q0) on the day of the control (test-day). The collected volume was then multiplied by two:

$$\text{Daily Milk Yield} = \left[\frac{\text{Q0} \times 2}{13}\right] \times 24 \ldots \left({}^{1}\!/_{\text{jr}}\right)$$

Q0 is the volume collected from two quarters (anterior and posterior).

After recording the weight of the sample, we collected a milk sample and placed it in a sterile tube (50 mL). This sample was immediately transported to the DEDSPAZA laboratory for analysis. The samples were stored and transported in a cooler, and were analyzed to determine the fat and protein levels using a milk analyzer Lactoscan SAP50 for each sampling day. The calibration of Lactoscan is imperative due to discrepancies observed in measurement parameters such as fat (Gerber method) and protein (Kjeldahl method). Calibration involves using a 4-L milk mixture from the study region, divided into two 2-L samples. Formalin (1 mL/L milk) was added to each sample, mixed thoroughly, and 250 mL of each sample was refrigerated for 12–24 h. Milk substrate is extracted using a thin tube, and low-fat milk was obtained. Combining the remaining milk from both samples yields high-fat milk (Fig. 5). Fat and protein content are determined using the Gerber and Kjeldahl methods, respectively, with three analyses per sample and then calculate the mean value for each parameter of the sample. To achieve specific fat content targets, low-fat and high-fat milk were mixed, aiming for 2–2.3% and 5–5.3% fat, respectively (Fig. 5). The medium-fat sample is a 1:1 mixture with an average of approximately 3.6% fat. Results are entered into the Lactoscan SAP50, selecting the calibration mode for camel milk. Five analyses were performed, and a recalibrated display confirms successful calibration for camel milk ("Cal: Camel").

Lactation traits and reproduction performance

Lactation length (LL): the lactation length (LL) of the studied camels is the sum of the intervals between the start of lactation and the first control, subsequent controls, and the last control and the end of lactation (drying off), as reported by the breeders and recorded in the survey of the studied farms.

Total milk yield (TMY) (Fleischmann's formula): the TMY is obtained by multiplying the first interval by the amount of milk obtained at the first control, the following intervals by the mean of the amounts of milk obtained at the follow-up controls, the last interval (between the last control and drying off) by the amount of milk obtained at the last control. All the products obtained are added together.

$$\mathrm{TMY} = Nc1 + i1\frac{C1 + C2}{2} + \cdots + i(n-1)\frac{Cn - 1 + Cn}{2} + pCn$$

N is the number of days between calving and control 1 (*C1*), *C1* is the first control, *C2* is the second control, *Cn* is the last control, $Cn-1$ is the second-to-last control, $i1$ is the number of days between C1 and C2, $i(n-1)$ is the number of days between the second-to-last control and the last control, and p is the number of days between the last control and drying off.

Total fat yield (TFY) and total protein yield (TPY): in the same way as the method for calculating the total amount of milk per lactation, we calculated the total amount of fat and protein per lactation.

Daily milk (DMY), fat (DFY), and protein (DPY) yields: the DMY is calculated as the ratio of the TMY to LL. Similarly, the average daily amount of milk fat (DFY) and protein (DPY) is calculated by dividing TFY and TPY by the LL, respectively.

Persistence coefficient (PC): this indicator is used to assess the persistence of camel milk production over time. In other words, it measures the ability of an animal to maintain its milk production at a high level over a long period of time after the initial lactation peak.

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

n is the number of controls, Pmax is the maximum production (peak), $P1$ is the production at the first control, $P2$ is the production at the second control, $P3$ is the production at the third control, Pn is the production at the last control, and $Pn-1$ is the production at the penultimate control.

Milk production in reference lactation (MPY_{stand}): in camels, the theoretical duration of lactation is 12 months. However, the reality is often different. The lactation duration is sometimes shorter, but more often it is longer (less interesting situation). In fact, we measured the amount of milk over a reference period of 365 days for all camels studied in order to compare their milk potential in this standard duration.

Lactation curve: the individual and herd lactation curves were generated from milk recording results "test-day records." They provide a description of the daily milk production over time for the average she-camel in the study conditions. The following parameters were identified on the average lactation curve: lactation length (LL), total production (TMY), maximum production (Peak), date of maximum production (t_{peak}), duration of the ascending phase, duration of the descending phase, slope of the curve during the descending phase, and persistence (PC).

Date of peak (t_{peak}): is the day on which a female animal produces the most milk during a lactation period (LL).

Inter-calving interval (ICI): the ICI is the period between two successive calving.

Days open (DO): is the calving-to-conception interval (days open) calculated as the period between calving and the following conception of the female camel.

Lactation curve and their parameters

To estimate the parameters of the lactation curve, fat, and protein, Wood's incomplete gamma function (1967) was used to fit these curves for she-camels in the two types of farms: $y(t) = \alpha^{t\beta} e^{(-\gamma t)}$. With $y(t)$ is the daily milk yield on day t, α, β, and γ are the parameters linked respectively to the production at the beginning of lactation, the ascending phase, and the descending phase. From the above model, the lactation parameters (α, β, and γ) were individually estimated and the lactation was adjusted. The peak, peak date, and lactation persistence are the indices that characterize one curve from another:

The time required to reach the maximum milk production (t_{peak}) was also calculated by dividing the slope of the milk production increase (β) by the slope of the milk production decrease (γ), and the peak period is calculated by the equation: $t\mathrm{peak} = \beta/\gamma$.

The peak of lactation is the point at which the female reaches the highest daily milk production during the lactation period. Using Wood's adjustment, it is calculated by the equation: $\text{Peak Yield} = \alpha\left(\frac{\beta}{\gamma}\right)^{\beta} e^{-\beta}$.

Statistical analysis

The SPSS software (version 24) was used to perform a statistical analysis of the data. Production and curve data were classified into two groups based on the livestock system (semi-intensive and intensive). An independent samples *t*-test was performed. We used this test after ensuring that the distribution conditions were normal to ensure its validity (normality test). The coefficient of determination (R^2) was obtained for each animal between the actual (current) milk production and the predicted milk production by the curve components (for milk yield "*MY*," fat, and protein). Results were considered statistically significant at $p < 0.05$.

Results

Milk production and lactation traits

During 12 months of lactation, the milk production volume (TMY) ranged from 1921.79 to 3111.26 kg, with an average volume of 2696.39 ± 343.86 kg. The lactation length (LL) ranged from 365 to 427 days, with an average of 398.38 ± 20.65 days. The average daily milk yield (DMY) was 6.77 ± 0.82 kg/day. The peak was 6.79 ± 0.68 kg, and the number of days to reach maximum production (t_{peak}) was 93.9 ± 55.8 with a production of 5.27 ± 0.94 kg at the beginning of lactation (Table 1). The persistency of lactation (CP) varied between 92.76 and 100.55%, with an average of 95.42% ± 2.52%. The average production, converted to reference duration of 365 days, is equal to 2506.98 ± 316.71 kg. The average total amounts of fat (TFY) and protein (TPY) per lactation are 164.99 ± 35.07 kg and 178.63 ± 9.71 kg, respectively. The mean fat rate (MFR %) and protein rate (MPR %) levels in the animals studied were 4.15 ± 0.91% and 4.49 ± 0.20%, respectively. The average peak *MFR* level was 4.94 ± 0.95%, and the average peak MPR level was 3.65 ± 0.23%. The number of days to reach the peak *MPR* was 142.5 ± 122.7 days and the duration to reach the peak *MFR* was 177.6 ± 150.9 days.

Table 1 Descriptive statistics for the lactation characteristics, days open, and inter-calving interval of Sahraoui the dairy camel milk from the north eastern Algeria

	N	Mean	SD	Min	Max
Age (years)	13	11.23	4.15	6	20
Parity number	13	3.62	2.10	1	8
LL (day)	13	398.38	20.65	365	427
TMY (kg)	13	2696.39	343.86	1921.79	3111.26
TFY (kg)	13	164.99	35.07	123.36	244.64
TPY (kg)	13	178.63	9.71	165.63	202.05
DMY (kg)	13	6.77	0.82	5.27	7.83
P_{eak}MY (kg)	13	6.79	0.68	5.93	8.45
T_{peak}MY (days)	13	93.9	55.8	18	194.1
MFR (%)	13	4.15	0.91	3.10	6.09
P_{eak}FR (%)	13	4.94	0.95	3.55	6.91
T_{peak}FR (days)	13	177.6	150.9	3.9	372
MPR (%)	13	4.49	0.20	4.18	4.79
P_{eak}PR (%)	13	3.65	0.23	3.38	4.1
T_{peak}PR (days)	13	142.5	122.7	339.9	18
MPY_{stand} (kg/365 days)	13	2506.98	316.71	1921.79	2963.30
PC (%)	13	95.42	2.52	92.76	100.55
DO (days)	13	348.38	30.33	303	396
ICI (days)	13	723.38	30.33	678	771

LL, lactation length; *TMY*, total milk yield (kg); *TFY*, total fat yield (kg); *TPY*, total protein yield (kg); *DMY*, daily milk yield (kg); $P_{eak}MY$, peak milk yield (kg); $T_{peak}MY$, time of peak milk yield (day); *MFR*, milk fat rate (%); $P_{eak}FR$, peak fat rated (%); $T_{peak}FR$, time of peak fat rate (day); *MPR*, milk protein rate (%); *PeakPR*, peak protein rate (%); $T_{peak}PR$, time of peak protein rate (day); MPY_{stand}, milk production per standard lactation (365 days); *PC*, persistency coefficient (%); *DO*, days open (day); *ICI*, inter-calving interval (day)

Lactation traits according to the breeding systems

Table 2 explains the influence of animal management system on milk production and its characteristics. Statistical analysis revealed that management system had a significant influence ($p < 0.05$) on total fat and average milk protein rate (MPR) of daily protein, but had no significant effect ($p > 0.05$) on total milk production, average daily milk yield (DMY), lactation duration (LL), daily fat (MFR), and total protein produced (TPY). She-camels raised in intensive system (2795.39 ± 261.88 kg/lactation) were more productive than those raised in semi-intensive system (2580.89 ± 414.43 kg/lactation). The same trend was observed for the average reference production MPY_{stand} (2574.26 ± 265.83 kg produced by she-camels in the intensive system, and 2428.48 ± 377.10 kg in the semi-intensive system). The same observation was made for the daily milk production (DMY); animals in the intensive system produced an average daily amount (6.96 ± 0.66 kg/day) higher than females in other livestock systems (6.55 ± 1.00 kg/day). The TFY (kg) is 182.02 ± 33.91 kg/lactation and 145.13 ± 26.30 kg/lactation in intensive and semi-intensive systems, respectively. The TPY is 176.27 ± 7.87 and 181.38 ± 11.62 kg/lactation for the intensive and semi-intensive systems, respectively. The production duration (LL) is longer in the intensive system (402.14 ± 21.18 days) than in the semi-intensive system (394 ± 21.03 days).

Table 2 The impact of management system on camel milk production (mean ± SD)

	Management system		Sig. (two-tailed)
	Semi-intensive ($n = 6$)	Intensive ($n = 7$)	
	Mean ± SD	Mean ± SD	
Age (ans)	12.17 ± 5.64	10.43 ± 2.51	0.475
Parity	4.00 ± 2.83	3.29 ± 1.38	0.565
LL (day)	394 ± 21.03	402.14 ± 21.18	0.503
TMY (kg/lactation)	2580.89 ± 414.43	2795.39 ± 261.88	0.281
DMY (kg/jr)	6.55 ± 1.00	6.96 ± 0.66	0.393
DO (day)	337.17 ± 26.26	358.00 ± 32.12	0.232
ICI (day)	712.17 ± 26.26	733.00 ± 32.12	0.232
TFY (kg/lactation)	145.13 ± 26.30	182.02 ± 33.91	0.045*
MFR (%)	3.69 ± 0.65	4.55 ± 0.95	0.087
TPY (kg/lactation)	181.38 ± 11.62	176.27 ± 7.87	0.366
MPR (%)	4.60 ± 0.13	4.39 ± 0.20	0.046*
PC (%)	94.56 ± 1.74	96.15 ± 2.97	0.275
MPY_{stand} (kg/365 days)	2428.48 ± 377.10	2574.26 ± 265.83	0.43

For the abbreviations, please see the legends of Table 1. Results with asterisk (*) were considered statistically significant at $p < 0.05$

The results in Table 2 showed no significance of the breeding system on the open day (OD) and the inter-calving interval (ICI), but they are relatively higher in the intensive system than in the semi-intensive system, where the results were respectively (358.00 ± 32.12 vs 337.17 ± 26.26 for the OD and 733.00 ± 32.12 vs 712.17 ± 26.26 for ICI) (Table 2).

Lactation, fat, and protein curves

Table 3 and Figs. 6 and 7 show the overall lactation curve and the effect of management system on parameters of lactation curves of dairy camels. The average initial milk yield ("α") of the she-camels, estimated by Wood, was equal to 5.95 ± 0.68 kg in the semi-intensive system and 4.69 ± 0.73 kg in the intensive system. The parameter of the lactation curve of the ascending slope ("β") to the maximum yield ("peak") varied according to the management system: 0.18 ± 0.24 in semi-intensive and 1.40 ± 0.54 in intensive livestock system. The declining slope parameter "γ" for different systems was − 0.41 ± 0.10 and − 0.36 ± 0.19 for the semi-intensive and intensive systems, respectively. This study showed that the mean times to reach peak yield (in days) were 11.58 ± 14.57 days and 179.51 ± 162.29 days, respectively, in the semi-intensive

Table 3 Effect of management system on parameters of lactation curves of dairy camels (mean ± SD)

		Management system		Sig. (two-tailed)
		Semi intensive ($n = 6$)	Intensive ($n = 7$)	
Milk yield	α	5.95 ± 0.68	4.69 ± 0.73	0.008**
	β	0.18 ± 0.24	1.40 ± 0.54	0.000**
	γ	− 0.41 ± 0.10	− 0.36 ± 0.19	0.581
	t_{peak}(day)	11.58 ± 14.57	179.51 ± 162.29	0.029*
	R^2	0.62 ± 0.28	0.35 ± 0.51	0.282
Fat yield	α	3.59 ± 1.40	4.70 ± 0.70	0.092
	β	0.16 ± 0.16	0.04 ± 0.12	0.166
	γ	− 0.17 ± 0.38	− 0.12 ± 0.23	0.781
	R^2	0.12 ± 0.10	0.13 ± 0.17	0.906
Protein yield	α	3.58 ± 0.28	3.36 ± 0.18	0.110
	β	0.00 ± 0.03	0.06 ± 0.07	0.120
	γ	− 0.28 ± 0.37	− 0.08 ± 0.20	0.237
	R^2	0.03 ± 0.03	0.11 ± 0.07	0.028*

α, the initial yield; β, the increasing slope of the curve; γ, the decreasing slope of the curve; R^2, coefficient of determination of variation; **significant at $p < 0.01$, *significant at $p < 0.05$

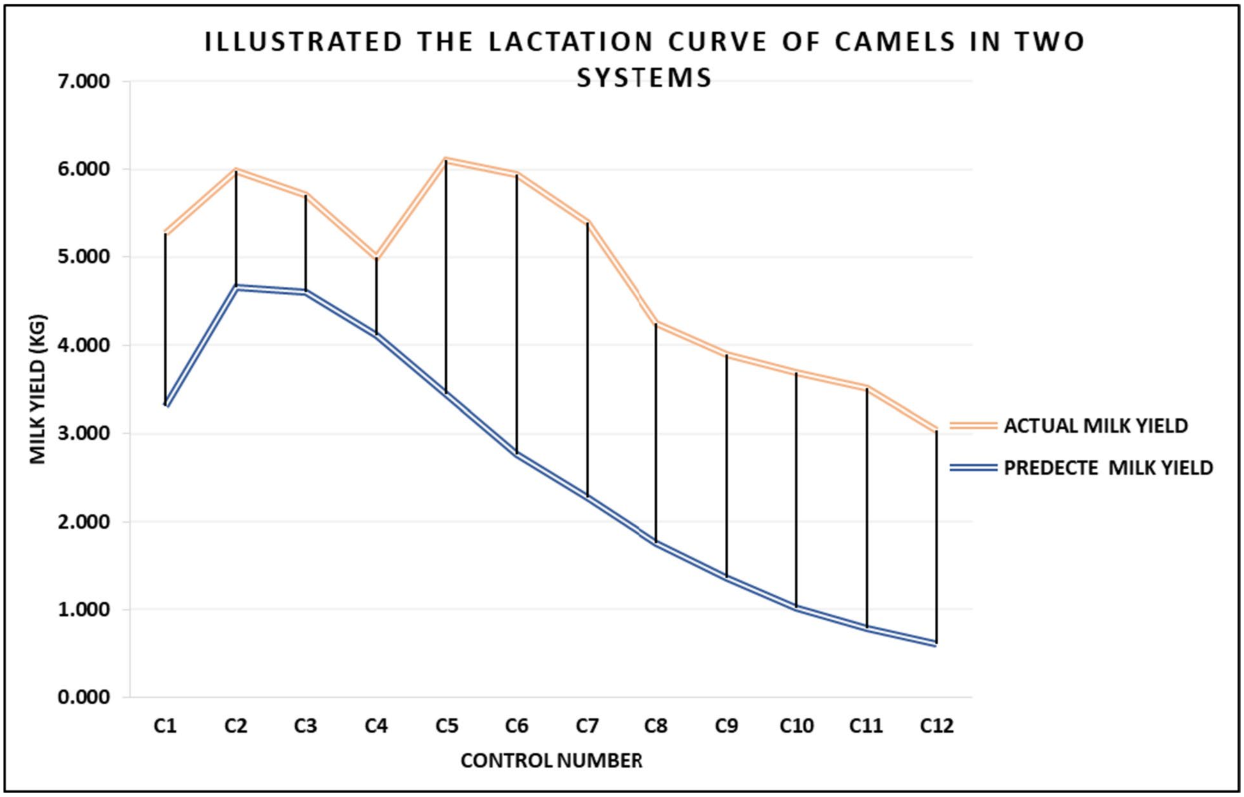

Fig. 6 The average general actual and predicted lactation curve of the studied female camels ($n = 13$)

and intensive systems. In terms of the parameters that determine lactation curves, the results revealed that the "α" parameter of the milk production is affected by the management system ($p = 0.008 < 0.01$), and it was noticed that this parameter "α" is higher in the semi-intensive system (5.95 ± 0.68) than in the intensive system (4.69 ± 0.73), while the parameter "β" of the milk production at the 1% threshold showed a highly significant ($p = 0.000 < 0.01$) relative superiority in the intensive system (1.40 ± 0.54) compared to semi-intensive farming (0.18 ± 0.24). There is a significant influence of the management system on the peak time of milk production (T_{peak}MY) ($p = 0.029 < 0.05$). In the intensive system (179.51 ± 162.29 days), the time to reach the peak is significantly later than in the semi-intensive system (11.58 ± 14.57 days). The coefficient of determination (R^2) for protein was also significantly different at the 5% ($p = 0.028 < 0.05$), in favor of the intensive system (Table 3). However, the "β" parameters of fat and protein, the "γ" parameter of milk yield, fat and protein, and the coefficient of determination (R^2) of milk yield and fat were not significantly ($p > 0.05$) affected by the management system.

Discussion

In Algeria, there is a noticeable gap in research concerning the potential of camel milk production in various management systems. This study aims to shed light on the milk potential of Algerian she-camels, specifically of the Sahraoui breed as the dominant camel breed in the South East of Algeria (El OUED), managed under both semi-intensive and intensive systems. The objective is to compare the impact of these husbandry systems on performance and lactation characteristics. For this purpose, thirteen she-camels were selected, comprising six from semi-intensive and seven from intensive systems. The mean age of the female camels was 11.23 ± 4.15 years, with specific averages of 12.17 ± 5.64 years and 10.43 ± 2.51 years for the semi-intensive and intensive systems, respectively.

The average milk production, as recorded in this study, did not showed a significant difference between the two livestock systems. The overall mean was 2696.39 ± 343.86 kg per lactation, with a range of 1921.79 to 3111.26 kg per lactation. The lactation length varied, ranging from 8 to 18 months, longer than that of dairy cows under similar conditions (Faye, 2004;

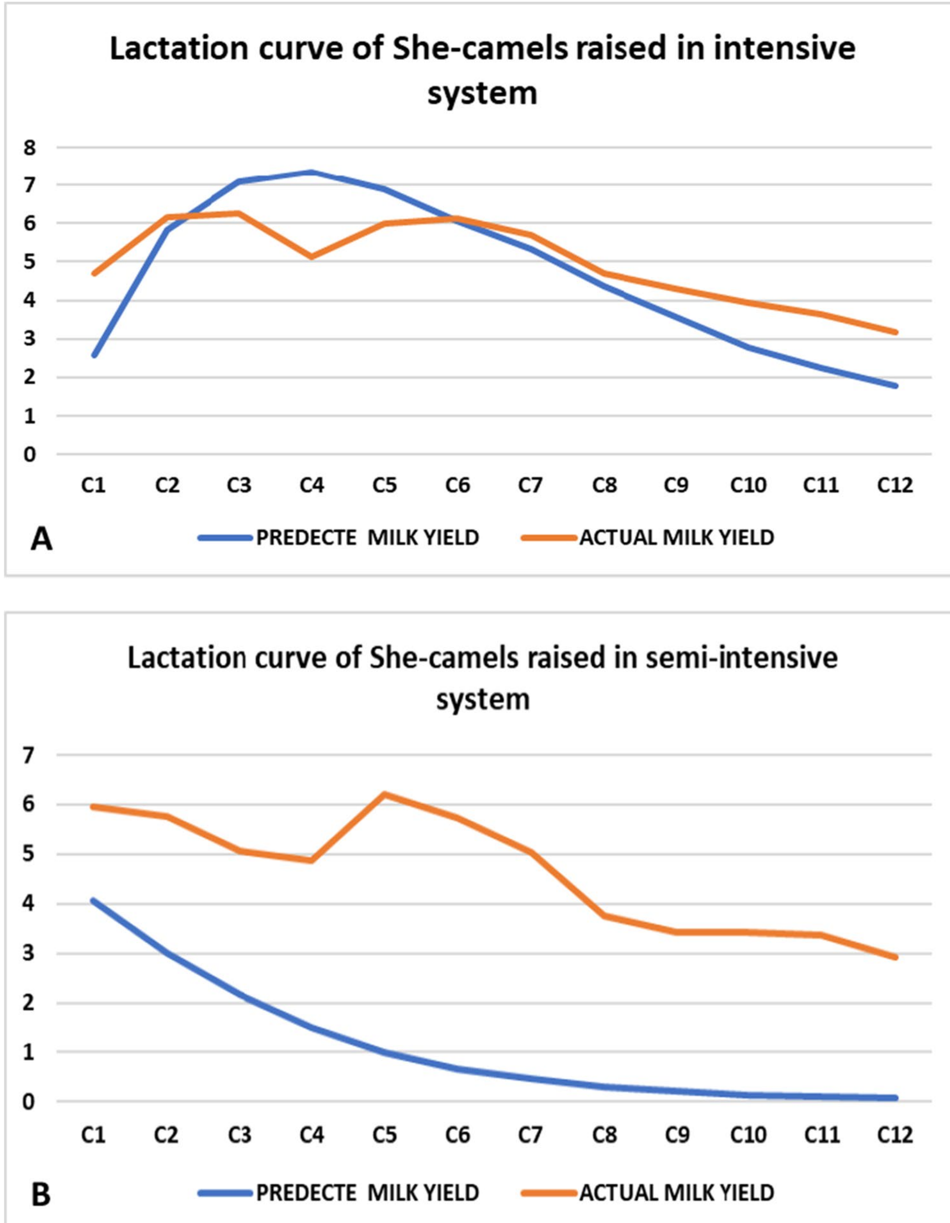

Fig. 7 Actual and predicted lactation curve according to the breeding systems of the Sahraoui female camels form the southeastern Algeria (**A** intensive system, **B** semi-intensive system)

Eulmi et al., 2023). Camel lactation curves are comparable to those of cattle but exhibit better persistence and a slower decline (Richard and Gerard, 1985). The lactation length is intricately linked to the length of the calving interval, which itself relies on the days open. In our study, the average inter-calving interval (ICI) and days open (DO) were found to be 723.38 and 348.38 days, respectively. These results align with a prior study conducted by Gherissi et al. (2020) in the same region, focusing on a similar camel population, whose reported an average ICI of 22.32 months (669.6 days) and an average DO of 340 days.

In the present study, the average milk production was calculated over a lactation period ranging from 365 to 427 days (averaging 398.38 ± 20.65 days), approximately 13 months. These results were relatively higher than those reported by Chamekh et al. (2020) in southern Tunisia, where lactation production was 1388.41 ± 575.46 L over an average period of 324 ± 57 days. Similarly, our findings exceed those of Ishag et al. (2017) in Sudan, reporting an average of 1378 ± 806.35 L/lactation over 347.45 ± 107.82 days, and Nagy and Juhasz (2016), who reported an average of 2320 ± 45 kg for a 400-day lactation.

Furthermore, the milk production potential of the she-camels in our study, raised in South-Eastern Algeria, is comparable to that reported for dromedaries in North Tunisia, averaging 2642 ± 523 L during a 390-day lactation (Jemmali et al., 2016). Regarding the average daily milk yield (6.77 ± 0.82 kg/day), it is relatively high compared to values reported in Tunisia (Chamekh et al., 2020: 4.21 ± 1.98 L/day), in the desert of Punjab in Pakistan for Marshabreed camels (Faraz et al., 2018: 5.62 kg/

day), and in Sudan (Ishag et al., 2017: 3.89 ± 1.80 L/day), but closer to those reported by Jemmali et al. (2016) in Tunisia (6.72 ± 2.46 L/day) and Nagy and Juhasz (2016) in the UAE (6.9 ± 0.10 kg/day). However, studies conducted in other parts of the world have reported higher daily milk yields, such as the performance of the Barela breed under extensive breeding conditions in Pakistan (Faraz et al., 2020: 7.38 L/day) and camels raised under an extensive system in Central Punjab, Pakistan (Ahmad et al., 2012: 8.17 ± 0.09 L/day). In Algeria, the available literature is inconclusive, showing a wide range in the daily milk produced by she-camels, ranging from 0.5 to 10 kg per day during an average lactation of 9 to 14 months (Chehma 2003; Adamou and Boudjenah, 2012). The morphological variability within the studied Sahraoui camel population (Meghelli et al., 2020; Gherissi et al., 2022; Dich et al., 2023), especially the anatomical traits associated with milk production potential (Dioli et al., 2023), may contribute to the disparities in results among different authors. In the existing literature, data indicate a significant difference in milk production between different camel breeds (Ismail and Mutairi 1998; Nagy and Juhasz 2016; Elkhair et al., 2017). Factors such as the method of milking (machine or hand), milking frequency (once, twice, or three times a day), and milking intervals all impact milk yield (Ayadi et al., 2009). The precise genetic evaluation of milk traits in camel species is relatively rare (Nagy and Juhasz 2016).

In terms of non-genetic factors, total milk yield is influenced by various elements, including the livestock system, health statute, quality and quantity of feed and water, seasonal variations and lactation stage (Elkhair et al., 2017; Benmeziane-Derradji 2021), age, parity, season, nutrition, and management (milking frequency, presence of calf) (Faye 2004; Raziq et al., 2010; Nagy and Juhasz 2016). The mortality of the calf has been observed to have a noteworthy impact on total milk yield (Abdalla et al., 2015). The authors showed that the she-camels, which lose their calves early, undergo a spontaneous, progressive early lactation decline immediately after the death of their calves, making milking difficult. Generally, total milk yield experiences a significant decrease when camel calves die during lactation, compared to those that are carried to weaning (Abdalla et al., 2015).

In the study area, camel herders report that she-camels that lose their calves early go into a spontaneous progressive early lactation decline immediately after the death of their calves and are then difficult to milking. In general, total milk yield decreased significantly when camel calves died during lactation, compared to those that carried camels to weaning (Abdalla et al., 2015). In the literature, some data show a significant difference in milk production between the different camel breeds (Ismail and Mutairi 1998; Nagy and Juhasz 2016; Elkhair et al., 2017). The method of milking (machine or hand), milking frequency (once, twice, or three times a day), and milking intervals all affect milk yield (Ayadi et al., 2009). Precise genetic evaluation of milk characters is rare in this species (Nagy and Juhasz 2016). According to the lactation stage, the results of the present study on milk production are in agreement with Wernery et al. (2004), who reported a significant decrease in production with increasing lactation stage. However, Zeleke (2007) showed no reduction in milk production until the 9th month of lactation.

In our study, the observed increase in milk production during the initial stage of lactation in she-camels, with a peak at 93.9 ± 55.8 days, aligns with findings from several authors, including Kamoun (1995), Adamou and Boudjenah (2012), Bakheit et al. (2016), Jemmaliet al. (2016), and Ayadi et al. (2019). These authors reported maximum milk production during the 3rd to 4th months of lactation. However, there are variations in peak milk production timing reported by different studies, with some other authors documenting maximum production during the 4th, 5th, and 7th months of lactation (Jemmali et al., 2016; Chamekh et al., 2020; Hadef et al., 2021). Our lactation curve profile results align with Wernery et al. (2004), who reported a significant decrease in production with an increasing lactation stage. However, Zeleke (2007) found no reduction in milk production until the 9th month of lactation. The decrease in milk production over time could be attributed to factors such as rising ambient temperatures, increased water requirements for camels during the dry season, and reduced availability of feed. The observed variation in persistence among camels, compared to dairy cows, for example, may explain the absence of a clear peak regardless of lactation length (Musaad et al., 2013a, b). The ascending phase, characterized by an increase in milk production due to rapid activation of specialized epithelial cells in the mammary gland, leads to a peak that may sometimes be sustained to form a plateau phase. This is followed by a more extended descending phase, lasting two-thirds of the lactation, corresponding to a phase of cellular regression (Macciotta et al., 2008).

The overall mean fat and protein rates in our study were 4.15 ± 0.91% and 4.49 ± 0.20%, respectively, corresponding to 41.5 ± 9 g fat and 44.9 ± 2.0 g protein per 100 mL of milk. These levels are considered higher when compared with those reported by Hadef et al. (2021) for the Tergui breed originate from the Adrar region of South-Central Algeria (fat = 30.95 ± 1.26 g/L and protein = 32.76 ± 0.48 g/L). The variations in camel milk quality may be attributed to candidate genes and metabolic pathways (Yao et al., 2023), seasonal changes in feed quality (management system), and environmental factors (Musaad et al., 2013b; Ayadi et al., 2019; Chamekh et al., 2020). However, Nagy et al. (2017) suggested that seasonal changes were independent of nutritional factors and milk quality is primarily related to environmental factors. Furthermore, the lactation number was found to influence the protein and fat contents in milk, with the first lactation characterized by the highest content of protein and fat (Al-jumaah et al., 2012; Abdalla et al., 2015). Otherwise, fat and protein rates in our study were higher to those reported by Konuspayeva et al. (2009), Ahmad et al. (2012), Musaad et al. (2013b), Abdalla et al. (2015), Nagy et al. (2017), Hadef et al. (2018), and Chamekh et al. (2020) in foreign camel breeds. The Sahraoui camel has never undergone genetic improvement of its milk production quantity which could explain the absence of genetic selection antagonism between milk quantity and quality (fat and protein rates) (Gherissi and Lamraoui 2022).

Analyzing the results based on the breeding system, our study on the average daily milk production and lactation duration of Sahraoui camels in the El Oued region under the semi-intensive system exceeded those reported by Adamou and Boudjenah (2012) in southeastern Algeria (4.8 L/day for a 9-month lactation). Hadef et al. (2021) reported Tergui she-camels in the Adrar region of South-Central Algeria produced 5.94 L/day during a 7-month lactation period. In comparison, camels in Bir Naam in South-East Algeria, according to Hadef et al. (2018), produced 3.96 ± 1.24 L/day during a 9-month lactation period. In Mauritania, sub-urban farms produced an average of 3.1 to 4.3 L/day, with an average of 684 l in 6 months (the first 3 months reserved for the calves) (Martinez 1989). Our results were higher than those published by Ishag et al. (2017: 2.80 ± 0.53 L/day) over an average lactation period of 326.93 ± 108.97 days, and Chamekh et al. (2020: 3.19 ± 0.79 L/day), but lower than those reported by Bakheit et al. (2016: 8.36 ± 1.64 L/day over 12 months) in Sudanese she-camels.

The recorded camel milk traits from herds practicing the intensive system (2795.39 ± 261.88 kg/lactation, with a daily milk yield of 6.96 ± 0.66 kg/day for an average lactation duration of 402.14 ± 21.18 days) are better than those reported in similar breeding system in southern Tunisia (Chamekh et al., 2020) and Saudi Arabia (Musaadet al., 2013a, b; Bitaraf Sani et al., 2022). However, they are comparable to those obtained by Ishag et al. (2017) in Sudan. This variation is likely due to the effects of breed (genetic performance), husbandry systems (sedentarization), animal feed, and health status (Benmeziane-Derradji 2021). Interestingly, no significant difference was found between the two management systems, intensive vs. semi-extensive, regarding the total milk yield per lactation. Our results contrast with those reported by Ayadi et al. (2018), who found that camels raised in an intensive system produced more milk than those in semi-intensive systems. On the contrary, Babiker and El-Zubeir (2014) and Chamekh et al. (2020) revealed that the milk production per lactation of female camels raised in a semi-intensive system is higher than that of camels raised in an intensive system. Intensification can be achieved through various means, including the use of advanced technologies, genetic selection of animals, and increasing animal density. It allows for higher milk production but is also more expensive (feed, labor, etc.) and can have a negative impact on animal welfare, influencing production. In contrast, the semi-intensive system involves milking animals and releasing them into natural pastures during part of the day, returning them to an enclosure in the evening (with young separated). This husbandry method allows animals to feed on grass and Saharan plants, promoting better welfare. The study results clearly demonstrate the significant contribution of management systems to the total fat yield (kg/lactation) and the daily protein yield ($p < 0.05$). However, no significant difference at the 5% level (Table 2) was observed for other parameters. According to Babiker and El-Zubeir (2014), high protein levels in she-camel milk in a semi-intensive system were reported. Al-jumaah et al. (2012) also recorded higher protein content in the semi-intensive system, while the highest fat content was found in the intensive system. Nevertheless, other authors have reported no significant effect of the management system on the composition of camel milk (Ayadi et al., 2018, 2019; Chamekh et al., 2020).

In this study, the lactation curve parameters (α, β, and γ) for milk, fat, and protein were described using the incomplete gamma function. Only the two parameters "α" and "β" of milk production were found to be highly significant ($p < 0.01$), while the parameter "γ" was not significant. This result differs from those reported by Zayed et al. (2014) ("α, β" not significant and "γ" significant) and Ishag et al. (2017) ("α" significant and "β and γ" not significant). However, all three parameters for fat and protein were not significant. Regarding the determination coefficients (R^2) for milk yield and fat, there was no significance ($p > 0.05$), but it was significant for milk protein. For the milk yield R^2 coefficient, our results align with those of Ishag et al. (2017). The Wood model was found to be more appropriate in the semi-intensive system than in the intensive system based on the coefficient of determination ($R^2 = 0.62 \pm 0.28$ and 0.35 ± 0.51 for the semi-intensive and intensive systems, respectively). These results contradict those published by Ishag et al. (2017) and Jemmali et al. (2016). The lactation curve model or used function (incomplete gamma function) was appropriate to describe the lactation curve of camels under the semi-intensive livestock system to estimate the milk potential of camels but not to estimate the fat and protein content of camel milk.

In the study area, we observed that some camel owners market camel milk to cover certain expenses, whether for themselves or for their animals, including food and veterinary care. Amidst this, camel milk owners and sellers have shown increasing interest in selecting females with high milk production and a long lactation period. Furthermore, specialized camel milk factories, such as the "TIDJANE SOUF" dairy, have emerged, marketing pasteurized camel milk and its derivatives.

Conclusion

This study showed an interesting potential for milk production of Sahraoui camels in terms of quantity and quality, as well as a lactation length and peak lactation performance. The female camels exhibit low reproductive performance, mainly characterized by prolonged days open and inter-calving intervals. These performances are mostly similar between the intensive and semi-intensive systems. These results suggest that the semi-intensive system could be an adequate solution to maintain good milk production in female camels facing increasingly challenging conditions in extensive pastoral herding. This challenges the merit of intensifying camel farming systems, often associated with technical, financial, sanitary difficulties, and animal welfare concerns, without necessarily adding value to the production level. The findings of this study emphasize the need for further research on the genetic improvement of camel milk potential and the development of informed breeding programs aimed at enhancing dairy performance of this exceptional animal.

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Author contribution G.D.E. and T.M. conceived and designed the study; CM performed and analyzed the data; K.S and B.H helped shape the research; C.M. G.D.E., T.M, B.F.Z., and M.I. wrote and corrected the paper; G.D.E, TM, and G.S.B.S. critical review of the manuscript. All authors read and approved the manuscript.

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Data availability Not applicable.

Declarations

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

Consent to participate Not applicable

Consent for publication Not applicable

Competing interests The authors declare no competing interests.

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