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Physiological and biochemical changes in milk yield, composition, and blood lipid profile across lactation stages and seasons in Iraqi she-camels

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Abstract

This study aimed to investigate the effects of lactation stage and seasonal variation on milk yield, composition, blood biochemical parameters, and fatty acid profiles in dairy camels raised under the environmental conditions of Basrah Governorate. A total of 60 animals were monitored between August 2018 and April 2019. Milk samples were analyzed for fat, protein, lactose, total solids, and Fatty acid composition. Blood samples were collected to determine triglycerides, total cholesterol, and lipoprotein fractions, including low-density lipoprotein, high-density lipoprotein, and very low-density lipoprotein. The results revealed a significant decrease in milk yield from early lactation (2.69 ± 0.22 kg) to late lactation (2.50 ± 0.24 kg). Lactose content increased progressively, while fat and protein percentages declined as lactation advanced. Significant reductions were observed in blood triglycerides, total cholesterol, and all lipoprotein types across lactation stages. Fatty acid analysis showed specific changes: capric acid increased during mid-lactation, lauric acid fluctuated, and palmitic acid increased during late lactation. Seasonal analysis showed the highest milk yield in autumn and the lowest in spring. Lactose levels increased significantly across the seasons, while fat and protein contents declined. Total cholesterol was highest in summer and decreased significantly toward spring. A correlation analysis revealed strong relationships among milk components, particularly between protein and fat, and a notable negative association between lactose and low-density lipoprotein. In conclusion, the lactation stage and seasonal variation influence milk yield, composition, lipid metabolism, and fatty acid profiles, reflecting physiological adaptations in dairy camels.

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Introduction

Camels play a vital role in the livelihoods of many communities in arid and semi-arid regions due to their remarkable adaptability and multifunctional contributions, including milk, meat, transportation, and other essential resources (1,2). There has been a growing demand for camel milk and meat production, particularly in regions such as Africa and the Arabian Peninsula, where these animals are crucial to both subsistence and economic activities (2). Camel milk, in particular, supports the nutrition and livelihoods of pastoralist communities, serving as a reliable source of food and income throughout the year, thus contributing significantly to the economic stability of many

developing countries (2). Rich in proteins (including casein, whey, and essential amino acids such as valine, alanine, leucine, and isoleucine), camel milk also contains substantial amounts of minerals (such as copper, iron, magnesium, phosphorus, manganese, calcium, potassium, zinc, and sodium), vitamins (including A, B, C, D, and E), and a high percentage of water (3). Unlike other dairy animals, camels can survive and continue to produce milk even in extremely harsh environments characterized by high temperatures, drought, and limited grazing, all while being managed through traditional practices. Research on ruminants has shown that milk composition is heavily influenced by diet quality, and it is believed that raising animals in environments different from their natural habitat can alter their milk's nutritional profile. Studies have suggested that camels could achieve higher milk yields if raised under improved management conditions (2,4). This resilience under suboptimal conditions highlights the camel's unique adaptability; however, it also suggests that environmental and managerial factors play a crucial role in optimizing milk production. In this context, it becomes essential to consider the various biological and ecological elements that influence milk yield and quality. Indeed, the composition of camel milk is not fixed but varies according to several factors, including the animal's age, parity, lactation stage, management practices, sampling technique, and feed quality. Seasonal variations also play a significant role, with notable fluctuations in fat and total solids content typically peaking during winter and decreasing during the summer months (4). While the effects of seasonality and lactation stages on camel milk production and composition have been extensively studied in various regions, there remains a significant research gap in Iraq, where such investigations are still lacking.

Therefore, the present study aims to assess variations in camel milk yield, milk composition, and blood lipid profile across different lactation stages and seasonal changes in Iraq. Specifically, it seeks to evaluate milk yield, key compositional parameters, and blood lipids across various stages of lactation and seasons, and to explore correlations between milk biochemical characteristics and specific fatty acid profiles throughout the lactation period.

Materials and methods

Milk and blood sampling and analysis

This study involved 60 Iraqi she-camels, aged 4 to 5 years, during their second lactation season, conducted from August 4, 2018, to June 4, 2019. The animals were selected from local farms in the Basra region. Milk samples were collected during the morning milking session across three lactation stages: early lactation (first 70 days), mid-lactation (days 71 to 160), and late lactation (days 161 to 240). The camels were reared under traditional semi-extensive management, and their diet consisted mainly of natural pasture species, such as camelthorn (Alhagi maurorum) and white saxaul (Haloxylon salicornicum), as well as wheat bran and dates. The primary milk components-fat, protein, and non-fat solids-were measured weekly throughout the experimental period using a LactoFlash Funke Gerber analyzer (Germany) at the Dairy Chemistry Laboratory, Department of Food Industries, College of Agriculture, University of Basra. For blood analysis, serum biochemical parameters related to the lipid profile, including triglycerides, cholesterol, LDL (low-density lipoprotein), HDL (high-density lipoprotein), and VLDL (very low-density lipoprotein), were determined using diagnostic kits supplied by Biolab SA (France) according to the manufacturer's protocols for each parameter.

Estimation of fatty acids

Esterification was performed by combining 1 g of milk fat sample (in triplicate) with 5 ml of potassium hydroxide. The mixture was homogenized using an electro mixer (IKA, Germany) for 5 minutes. Subsequently, 5 mL of pure hexane was added, as described by Zaqeer *et al.* (5).

Fatty acid esterification

The esterification process was performed by mixing 1 g of sample (three replicates per sample) with 5 mL of potassium hydroxide in an IKA electro mixer (Germany) for 5 minutes, then adding 5 mL of pure hexane, as described in (5).

Fatty Acid Profiling by GC-MS

The fatty acid composition of the milk fat was analyzed using Gas Chromatography-Mass Spectrometry (GC-MS) in the laboratories of the Ministry of Science and Technology, Baghdad, following the methodology of Oh *et al.* (6). The samples were analyzed using an HP-5ms column and helium as the carrier gas, with a flow rate of 1 ml/min. The injector and interstitial carrier were set at 290°C. The GC oven was programmed as follows: initial temperature of 40°C, ramped to 300°C at 10°C/min, and held at 300°C for 20 minutes. The separated peaks were identified by comparing their spectra with the NIST 2014 database. Total fatty acids were categorized as follows (6): Saturated Fatty Acids (SFA): C12:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0. Monounsaturated Fatty Acids (MUFA): C14:1 c9 + C16:1 c9 + C18:1 c9. Polyunsaturated Fatty Acids (PUFA): C18:2 c9, c12 + C18:3n-3 + C18:2 c9, t11 + C20:3n-6 + C20:4 + C20:5 + C22:5. Unsaturated Fatty Acids (USFA): MUFA + PUFA (7).

Statistical analysis

Before statistical analysis, the data were adjusted for both seasonal and age-related effects by correcting for deviations from the mean age group and milk production season. Energy-corrected milk, fat-corrected milk, and protein-corrected milk were calculated as follows (8): Milk energy

(Kg/Kcal) =291.14 kcal/kg x Kg milk+10.944 kcal/kg x fat% % kg x Milk. Energy in 1 kg Corrected milk for 4% fat = 291.14 × 1 kg milk + 10.944× 0.04 fat. Statistical analysis was performed using Analysis of Variance (ANOVA) and Ryan's Least Significant Difference (RLSD) test to compare the means of the studied traits. Data were analyzed using a completely randomized design in SPSS (9). The following mathematical model was used for analysis: $Y_{ij} = \mu + \pi i + eij$. Whereas: Y_{ij} the j^{th} observation during i^{th} lactation stage, μ =common mean, P_i = the effect of i^{th} lactation stage (i= 3, beginning, middle, and end of lactation), E_{ij} = Effect of experimental error associated with j^{th} observation with zero mean and variance o^2 e. The relationships between the studied traits were also assessed using simple regression coefficients and stepwise regression within the same statistical program. y=a+ bx. y= a+b1x1 +b2x2.....+ bnXn. Correlation coefficients using DATAtab Team (10) were calculated between blood parameters and milk production and its components.

Results

The current study used 66 samples collected from different regions of the Nineveh Governorate. According to the National Mastitis Council (NMC) 2017 guidelines (29), S. aureus isolated from the milk samples accounted for 23 (34.8%). All the positive *S. aureus* isolates showed positive results in Gram, catalase, and coagulase tests. In addition, *S. aureus* was detected as round, golden-yellow clusters on mannitol salt media and hemolysis on the blood media. Furthermore, the study results demonstrated that the nuc gene was detected in 23 (34.8%) of S. aureus isolates (Figure 1). The PCR assay yielded results similar to those of the phenotypic determination tests. Regarding presence or absence, the mecA gene was detected in 12 (52.2%) of the 23 *S. aureus* isolates (Figure 2).

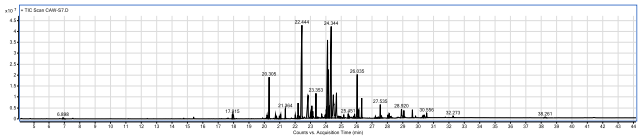

Figure 1: Fa Gas chromatographic profile of fatty acids extracted from camel milk. The peaks represent individual fatty acid methyl esters (FAMEs) separated by retention time. Major peaks observed at 20.305, 22.444, 24.344, and 26.035 minutes indicate the presence of prominent saturated and unsaturated fatty acids. The analysis was performed using Gas Chromatography (GC), enabling qualitative and semi-quantitative assessment of the milk's lipid composition.

Figure 2 represents the correlation matrix between various milk parameters, illustrating the relationships among these factors. Notably, protein and fat show a strong positive correlation (0.99), indicating that as protein levels increase, fat levels tend to grow as well. There is a significant negative correlation between protein and lactose (-0.98), suggesting that higher protein content is associated with lower lactose content. Additionally, triglycerides (TG) show positive correlations with both protein (0.85) and fat (0.84), further indicating their interdependence. Meanwhile, HDL shows slight positive correlations with protein and fat. Still, these relationships are weaker than those with the other mentioned factors. Lactose demonstrates a notable negative correlation with LDL (-0.53), indicating that lower lactose levels are linked with higher LDL.

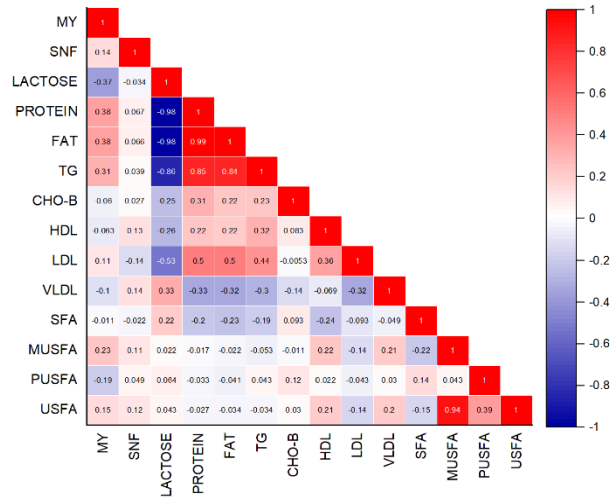

Figure 2: Heatmap of Pearson correlation coefficients between milk composition parameters (MY: Milk Yield, SNF: Solids-Not-Fat, LACTOSE, PROTEIN, FAT, TG: Triglycerides) and blood biochemical parameters (CHO-B: Blood Cholesterol, HDL, LDL, VLDL, SFA: Saturated Fatty Acids, MUSFA: Monounsaturated Fatty Acids, PUSFA: Polyunsaturated Fatty Acids, USFA: Unsaturated Fatty Acids) in lactating Iraqi she-camels. Positive correlations are shown in red, negative in blue, with intensity indicating the strength of correlation. Notably, strong positive correlations were observed between PROTEIN and FAT (r = 0.99) and between MUSFA and USFA (r = 0.94). In contrast, a strong negative correlation was observed between LACTOSE and PROTEIN (r = –0.98).

Table 1 highlights the significant impact of different lactation stages-first, middle, and last-on a comprehensive array of milk parameters. Milk yield shows a downward trend from 2.69±0.22 kg in the first stage to 2.5040± 0.23683 kg in the last stage, with a statistically significant difference (P = 0.025). Lactose content significantly increases across the stages, from 4.4275± 0.16849% to 5.3890±0.25637% (P = 0.000). Similarly, the protein percentage decreases from 4.0585± 0.17% in the first stage to 3.3025± 0.15% in the last (P = 0.000). Fat content also shows a significant decrease, with values shifting from 4.2995± 0.04% to 4.1140±0.03%

(P = 0.000). Both energy-corrected milk (ECM) and fat-protein-corrected milk (FPCM) exhibit similar downward trends, reflecting significant variation across lactation stages. Triglyceride levels notably reduced from 63.25±3.8 mg/dl to 46.10±2.84 mg/dl (P = 0.000). Cholesterol and its carriers show significant changes during lactation. Total cholesterol significantly decreases from the first to the last stage (P = 0.000). LDL (low-density lipoprotein) levels also show a significant reduction across stages, contributing to the overall decline in cholesterol. HDL (high-density lipoprotein) decreases significantly in later stages of lactation (P = 0.002). VLDL (very low-density lipoprotein) levels drop considerably from the first to the last stage, reflecting changes in triglycerides and overall lipid profiles (P = 0.000). In terms of fatty acids, there are notable shifts: C10% (capric acid) increases significantly in the middle stage compared to others (P = 0.033), C12% (lauric acid) shows considerable fluctuation throughout (P = 0.004), and C16% (palmitic acid) increases significantly by the last stage (P = 0.024). Although specific saturated fatty acids show these fluctuations, the overall percentage of saturated fatty acids remains statistically unchanged (P = 0.132).

Table 1: Impact of lactation stage on milk yield and composition, and blood parameters in Iraqi lactating she-camel

Parameters	Stage of lactation			P Value
	First	Second	Third	
Milk Yield (kg.)	2.69±0.22a	2.65±0.21a	2.50±0.24b	0.025
Solid Not Fat%	6.08±1.41	6.44±1.23	6.11±1.29	0.608
Lactose %	4.43±0.17a	4.87±0.12b	5.39±0.25c	0.000
Protein %	4.06±0.17a	3.65±0.09b	3.30±0.15c	0.000
FAT %	4.30±0.04a	4.21±0.02b	4.11±0.03c	0.000
Total Fat (kg.)	0.012±0.004a	0.0105±0.002ab	0.0100±0.00b	0.059
FATGMT	12.03±2.04a	11.92±1.98a	10.5420±1.59b	0.026
Energy corrected milk (kg.)	2.85±0.23a	2.75±0.22a	2.57±0.24b	0.002
Fat protein corrected milk (kg.)	2.93±0.24a	2.77±0.23b	2.52±0.25c	0.000
Fat corrected milk (kg.)	2.82±0.23a	2.73±0.22a	2.5480±0.24b	0.002
C4%	11.94±0.06	11.95±0.05	11.96±0.06	0.733
C8%	0.31±0.009	0.31±0.006	0.31±0.006	0.764
C10%	0.20±0.03a	0.22±0.02b	0.21±0.02ab	0.033
C12%	0.89±0.02a	0.87±0.01b	0.90±0.02a	0.004
C14%	11.90±0.25	11.87±0.32	11.93±0.22	0.774
C16%	22.62±0.71a	22.44±0.81a	23.15±0.91b	0.024
C18%	13.52±0.69	13.39±0.67	13.33±0.7	0.659
C20%	0.12±0.008	0.12±0.007	0.12±0.009	0.264
Saturated Fatty Acid%	61.54±1.17ab	61.22±1.21a	61.94±0.91b	0.132
C14:1C9%	0.46±0.02	0.47±0.02	0.48±0.02	0.288
C16:1C9%	4.46±0.15	4.49±0.15	4.50±0.12	0.551
C18:1C9%	16.10±0.28	16.14±0.32	16.09±0.29	0.892
C20:1C9%	0.10±0.01	0.10±0.01	0.10±0.02	0.871
Mono USFA%	21.13±0.32	21.22±0.31	21.19±0.32	0.712
C18:2C9.C12%	4.06±0.09	4.02±0.10	4.07±0.15	0.464
C18:3n3%	2.25±0.009	2.26±0.01	2.26±0.009	0.487
C20:3n6%	0.16±0.02	0.15±0.01	0.16±0.01	0.805
Poly USFA%	6.48±0.09	6.44±0.10	6.49±0.15	0.429
Unsaturated SFA%	27.62±0.34	27.66±0.35	27.68±0.33	0.845
Triglyceride (mg/dl)	63.25±3.80a	55.8000±4.34b	46.1000±2.84c	0.000
Cholesterol B(mg/dl)	132.75±13.09a	108.15±7.42b	123.50±3.77c	0.000
HDL (mg/dl)	67.65±19.10ab	76.25±14.07b	58.50±20.49a	0.012
LDL (mg/dl)	64.05±16.10a	60.20±17.93a	40.65±1.19b	0.000
VLDL (mg/dl)	17.35±3.57a	20.15±4.99a	20.50±3.79b	0.039

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Table 2 illustrates the impact of seasonal variations on milk production and composition, revealing significant changes in various parameters. Milk yield demonstrates a seasonal pattern, with the highest yields recorded in autumn (2.697±0.20781 kg) and a notable decrease in spring (2.4444±0.21703 kg), indicating a significant seasonal effect

(P = 0.037). Lactose content increases progressively through the seasons, from 4.3109±0.12825% in summer to 5.6122±0.21776% in spring, showcasing a highly significant seasonal influence (P = 0.000). Protein and fat percentages also decrease significantly from summer to spring, with P values of 0.000. Cholesterol levels exhibit notable seasonal differences; total cholesterol is highest in summer (136.4545±12.15 mg/dl) and decreases significantly throughout the year (P = 0.000). LDL shows a significant reduction in spring compared to other seasons (P = 0.000). At the same time, HDL and VLDL exhibit fewer clear patterns but still reflect the shifting lipid profiles, with VLDL variations nearing significance (P = 0.082). The analysis of fatty acid composition reveals a significant seasonal influence on C16% (palmitic acid), which increases substantially by spring (P = 0.037). Additionally, minor fluctuations in C201% are observed, indicating some seasonal variation (P = 0.052). Despite these individual changes, the overall saturated fatty acid content and other specific fatty acid percentages remain statistically stable across seasons.

Table 2: Impact of season on milk yield and composition, and blood parameters in Iraqi lactating she-camel

Parameters	Summer	Autumn	Winter	Spring	P value
Milk Yield (kg.)	2.65±0.24a	2.70±0.207a	2.57±0.23ab	2.44±0.22b	0.03
Solid No Fat%	6.43±1.56	6.34±1.28	5.76±1.12	6.46±0.91	0.37
LACTOSE%	4.31±0.13a	4.71±0.13b	5.14±0.11c	5.61±0.22d	0.000
PROTEIN%	4.17±0.13a	3.79±0.13b	3.47±0.06c	3.14±0.08d	0.000
FAT %	4.33±0.05a	4.24±0.02b	4.15±0.03c	4.08±0.03d	0.000
TOTAL FAT (kg.)	0.012±0.004	0.011±0.003	0.01±0	0.01±0	0.056
FATGMT	12.33±2.3a	12.14±1.98a	10.62±1.56b	10.51±1.24b	0.015
Energy corrected milk (kg.)	2.82±0.27ab	2.82±0.22a	2.66±0.24bc	2.49±0.22c	0.004
FPCM (kg.)	2.91±0.28a	2.86±0.24a	2.64±0.24b	2.42±0.22c	0.000
FCM (kg)	2.77±0.26ab	2.79±0.22a	2.63±0.24bc	2.47±0.22c	0.005
C4%	11.94±0.04	11.96±0.06	11.96±0.05	11.95±0.08	0.65
C8%	0.32±0.008	0.32±0.008	0.32±0.006	0.31±0.006	0.62
C10%	0.21±0.03	0.22±0.03	0.22±0.02	0.21±0.03	0.33
C12%	0.89±0.027	0.88±0.02	0.89±0.02	0.90±0.03	0.10
C14%	11.91±0.25	11.86±0.27	11.93±0.31	11.96±0.19	0.78
C16%	22.55±0.58a	22.49±0.91a	22.86±0.93ab	23.41±0.57b	0.03
C18%	13.45±0.73	13.61±0.59	13.20±0.68	13.30±0.80	0.30
C20%	0.13±0.009	0.13±0.008	0.12±0.008	0.12±0.009	0.20
Saturated Fatty Acid%	61.38±1.10	61.47±1.274	61.51±1.06	62.17±0.84	0.38
C14:1C9%	0.47±0.02	0.47±0.03	0.47±0.027	0.49±0.03	0.18
C16:1C9%	4.49±0.16	4.47±0.16	4.49±0.12	4.53±0.15	0.80
C18:1C9%	16.10±0.34	16.08±0.27	16.23±0.33	15.97±0.22	0.19
C20:1C9%	0.12±0.02a	0.11±0.01ab	0.11±0.02a	0.09±0.02b	0.05
Mono USFA%	21.18±0.32	21.13±0.31	21.31±0.32	21.09±0.28	0.25
C18:2C9.C12%	4.09±0.08	4.03±0.098	4.03±0.15	4.13±0.11	0.10
C18:3n3%	2.25±0.008	2.26±0.009	2.26±0.008	2.26±0.01	0.12
C20:3n6%	0.16±0.02	0.15±0.01	0.16±0.01	0.16±0.02	0.69
Poly USFA%	6.51±0.08	6.45±0.09	6.46±0.16	6.54±0.10	0.14
Unsaturated SFA%	27.69±0.37	27.58±0.32	27.76±0.35	27.63±0.33	0.40
Triglyceride (mg/dl)	64.73±2.28a	59.00±4.03b	48.29±4.68c	45.89±2.8c	0.000
Cholesterol B(mg/dl)	136.45±12.15a	115.43±13.86b	119.64±10.08b	122.00±2.54b	0.000
HDL (mg/dl)	72.64±16.67a	71.56±16.97a	65.06±22.68ab	55.22±17.12b	0.122
LDL (mg/dl)	60±12.17a	63.65±18.28a	55.12±21.55a	26.33±5.12b	0.000
VLDL (mg/dl)	17.27±2.53a	18.74±4.99ab	20.12±4.1061ab	21.89±3.59b	0.08

Means with different manuscripts for each item differ significantly at the 0.05 level.

Discussion

In the present study, milk yield declined, consistent with other ruminants (11). However, this decline is more moderate compared to other camel breeds, such as those reported by Nagy *et al.* (12). Higher milk yield in early lactation is driven by secretory epithelial cell (SEC) differentiation and proliferation during late gestation and

early lactation, mainly regulated by the PI3K-Akt pathway (13,14). Other factors, including parity, udder health, nutrition, and water availability, also influence production (11,15,16). The observed stability in solids-not-fat (SNF) levels contrasts with the expected decline across lactation stages. In contrast, Faraz *et al.* (17) reported SNF reductions in Marecha camels, attributed to nutrient reallocation and hormonal changes affecting protein and lactose synthesis. The decline in protein content observed in our study aligns with findings by Faraz *et al.* (17) and by Khalifa & Zakaria (18). Chamekh *et al.* (15) also observed fluctuations, highlighting the impact of milk yield on protein concentration. This overall decline is primarily attributed to mammary gland involution and the metabolic reallocation of amino acids for maintenance and fetal development (12). Lactose content significantly increased (P = 0.000). Hadef *et al.* (19) found relatively stable lactose levels across stages. Chamekh *et al.* (15) observed an inverse relationship between milk yield and lactose content, supporting the dilution effect as volume decreases. Total solids (TS) followed a distinct pattern, with higher values in early lactation. Hadef *et al.* (19) reported TS levels decreasing from mid-lactation, with a slight increase in late lactation. Chamekh *et al.* (15) found a similar trend. These changes align with the inverse relationship between milk yield and composition: the mid-lactation dip reflects nutrient dilution due to higher milk volume, while the late-lactation increase corresponds with reduced yield and solids concentration (18). Fat content declined significantly throughout lactation, consistent with findings by Faraz *et al.* (20). Similar decreases were reported by Ahmad *et al.* (21) and Hadef *et al.* (19), reflecting a metabolic shift that favors carbohydrate synthesis over lipid accumulation (22,23). Interestingly, Chamekh *et al.* (15) reported the lowest fat content at mid-lactation, likely due to reduced milk volume and concentration effects. Elhassan & Zubeir (24) also confirmed that fat percentages are significantly influenced by lactation stage, with higher fat levels in late lactation linked to lower milk yields. FPCM and FCM also declined significantly across lactation, reflecting trends seen in other camel breeds and ruminants (25). This decline is primarily due to progressive depletion of body fat reserves and a shift in metabolism toward maternal maintenance rather than milk synthesis (26). Similarly, energy-corrected milk (ECM) declined, consistent with patterns observed in dairy camels and cattle, in which ECM declines due to reduced mammary efficiency and shifting metabolic demands (12). Serum triglyceride levels declined significantly from early to late lactation (P < 0.001). This reflects the early dominance of de novo lipogenesis at parturition, which gradually subsides as dietary fatty acids become the primary lipid source for milk synthesis (27). Serum cholesterol exhibited a triphasic trend: highest in early lactation, significantly lower in mid-lactation, and moderately higher again in late lactation (P < 0.001). However, Mohebbi-Fani *et al.* (28) found no variation across stages in cows, indicating species-specific metabolic regulation. The slight rebound in late lactation may reflect reduced cholesterol utilization due to decreased milk yield, as also noted in pregnant camels (29). LDL levels decreased, indicating reduced lipid transport for milk synthesis. This pattern is supported by Skotnicka *et al.* (30), who reported that HDL concentrations peaked in mid-lactation. This pattern also aligns with camel studies (31).

This study revealed significant variations in fatty acid composition across lactation stages, reflecting metabolic adaptations in milk production. Notably, saturated fatty acids (SFA), particularly palmitic acid (C16:0), increased during late lactation (P = 0.024). In contrast, short-chain fatty acids such as capric acid (C10:0) and lauric acid (C12:0) fluctuated significantly (P = 0.033 and P = 0.004, respectively). These findings support previous research showing that as lactation progresses, lipid metabolism increasingly mobilizes long-chain fatty acids from body reserves (22,23). Although individual SFAs varied, the total SFA proportion remained stable across lactation (P = 0.132), in agreement with Chamekh *et al.* (15), who attributed this to compensatory lipid shifts. This suggests a consistent de novo synthesis of short- and medium-chain fatty acids in the mammary gland, as reported in dairy camels and small ruminants (32). A mid-lactation decline in de novo short-chain fatty acids (C6:0–C12:0) may reflect energy conservation mechanisms, as also observed by Ayadi *et al.* (33). Monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA) showed minimal variation (P = 0.712 and P = 0.429, respectively). However, a slight increase in oleic acid (C18:1n9) was noted in late lactation. This aligns with findings by Opgenorth *et al.* (22), who linked increased oleic acid to enhanced lipid mobilization and stearic acid desaturation. The relative stability of PUFA, including linoleic (C18:2) and α-linolenic acids (C18:3n3), indicates a regulated mechanism ensuring the availability of essential fatty acids for neonatal development (34).

This study investigates seasonal variations in the milk yield and composition in Iraqi Sha-camels. We observed distinct seasonal patterns in milk yield, lactose, protein, fat, and solids-not-fat (SNF) content. Milk yield peaked in autumn and declined in spring, consistent with findings by El-Hanafy *et al.* (35) in Saudi Arabian camels, who linked higher milk yields to improved forage availability and moderate climatic conditions. In contrast, Chamekh *et al.* (15) and Faraz *et al.* (17) in Tunisia and Pakistan, respectively, observed peak yields in summer, highlighting the influence of regional climates, breed adaptations, and feeding systems. Habte *et al.* (36) also noted the impact of the temperature-humidity index (THI), reporting a strong positive correlation between THI and camel milk production. The decline in milk yield during spring in this study is attributed to heat stress, reduced forage availability, and higher ambient temperatures, which increase metabolic energy expenditure and reduce energy for milk synthesis

(17,37). Lactose content, essential for regulating milk osmolarity (38), showed a significant seasonal variation, increasing from summer to spring, consistent with Musaad *et al.* (37). Heat stress likely contributes to increased lactose concentration as camels maintain osmolarity and hydration during hotter months (17,36). However, some studies, such as Shuiep *et al.* (4) and Nagy *et al.* (39), report contrasting findings, with either lower or minimal seasonal variation in lactose content. Comparative studies on Bactrian camels in Mongolia (40) and on Egyptian and Jordanian camels (41) also show that lactose levels vary with diet, climate, and water intake. A significant seasonal decline in protein content was observed, from summer to spring, aligning with findings by Ahmad *et al.* (21) and Bakry *et al.* (32). Additionally, the metabolic demand for thermoregulation in hotter months may drive enhanced protein biosynthesis due to increased energy availability (42). Seasonal variations in protein content are well documented in camels, with Musaad *et al.* (37) reporting higher protein levels in winter and lower levels in autumn. Habte *et al.* (36) found similar trends. However, Nagy *et al.* (39) and Chamekh *et al.* (5) reported minimal or opposite seasonal fluctuations, highlighting regional and management-dependent variations in protein levels. Fat content was highest in summer, aligning with Bakheit *et al.* (43), who found similar trends in other populations. The higher fat content in summer may be attributed to camels mobilizing stored lipids as an energy source during heat stress, thereby increasing fat incorporation into milk (38). El-Hanafy *et al.* (35) reported similar observations in Saudi Arabian camels. Contrasting studies by Chamekh *et al.* (15) found lower fat content in summer, suggesting that heat stress may prioritize thermoregulation over lipid synthesis. Ahmad *et al.* (21) also observed peak fat content during the rainy season, highlighting the influence of regional differences in forage and water availability on milk fat levels. The stability of SNF content suggests tight regulation by physiological mechanisms to maintain milk quality (32). Musaad *et al.* (37) similarly observed stable SNF values in Saudi camels, highlighting SNF's resilience to environmental fluctuations. Camels' ability to maintain SNF content may be due to efficient nitrogen metabolism and to prioritizing essential milk constituents over lipids under nutritional stress. However, other studies report contrasting results. Chamekh *et al.* (15) found that SNF levels peaked in winter and were lowest in summer, suggesting regional variations in forage composition and metabolic adaptations. Bakheit *et al.* (43) also observed significant seasonal changes in SNF content, linking these fluctuations to dietary quality and water intake. The present study observed significant seasonal variations in total fat content and FATGMT, with peak values in summer and the lowest in spring. Similar trends were reported by Musaad *et al.* (37) and Chamekh *et al.* (15), who linked peak milk yields to increased total fat secretion. Ahmad *et al.* (21) attributed higher fat production in hotter months to increased energy demands for thermoregulation and metabolic adaptation. Bakheit *et al.* (43) and Faraz *et al.* (17) also observed elevated fat and total solids contents in camels during dry months. However, contrasting findings exist: Haddadin *et al.* (41) and Shuiep *et al.* (4) reported peak fat levels during winter, likely due to improved forage quality and nutrient availability. Ahmad *et al.* (21) also noted that regional variations in feed composition, water availability, and environmental stressors can influence fat content in camel milk. In terms of ECM, FPCM, and FCM, this study found the highest values in summer, corresponding to higher fat and protein content. This is in line with the findings of AlSuwaiegh *et al.* (44), who observed enhanced ECM and FPCM in Holstein cows supplemented with functional feed additives, underscoring the role of nutrition in optimizing milk energy output. On the other hand, Habte *et al.* (36) reported no significant seasonal variations in ECM in Ethiopian camels, suggesting that breed and environmental factors differently influence milk energy yield across regions.

The fatty acid composition of Iraqi camel milk exhibited significant seasonal variations. As in other ruminants, these fluctuations are driven by pasture availability and climatic factors, which influence fatty acid synthesis and metabolic adaptations (45). SFAs were the predominant fraction across all seasons, with palmitic acid (C16:0) and stearic acid (C18:0) being the most abundant. Palmitic acid showed a significant increase in spring, consistent with previous findings that colder conditions and nutritional shifts elevate SFA levels by increasing fat mobilization for energy (46,47). In khainak milk, palmitic acid levels also peaked in winter, attributed to increased fat mobilization (47). However, Saroj *et al.* (48) reported higher SFA levels during summer, suggesting that heat stress-induced lipid mobilization may also elevate SFA content in some environments. Iraqi camels showed slightly lower overall SFA content in summer compared to Sudanese dromedaries, likely due to differences in pasture quality and climatic adaptation (49). MUFAs, predominantly oleic acid (C18:1n-9, cis), exhibited minor seasonal fluctuations. The highest concentration was observed in spring, followed by a gradual decline through summer and autumn, similar to trends observed in camels from Kazakhstan and Sudan (49). This aligns with findings in yak and khainak milk (47). PUFAs remained relatively stable across seasons, with linoleic acid (C18:2n-6) and alpha-linolenic acid (C18:3n-3) being the predominant PUFAs. A slight increase in PUFA content was observed in spring, likely due to improved forage quality, as also reported in Jordanian and Sudanese camels (46). Camel milk PUFA content was comparable to that of yaks but lower than mare's milk, which is particularly rich in linoleic and linolenic acids (45). The seasonal trends observed in Iraqi camels reflect regional variations, with palmitic acid increasing in spring, in contrast to studies showing that SFAs are higher in warmer months (48). Stearic acid (C18:0)

remained relatively stable across seasons (P = 0.304), consistent with findings in Sudanese and Kazakh camel milk, but contrasting with yak milk, where stearic acid showed seasonal fluctuations (47).

Triglyceride levels peaked in summer and autumn, with the lowest concentrations in winter and spring. This trend aligns with findings by Aichouni *et al.* (50). The summer increase in TG may be due to reduced forage quality, leading to lipid mobilization as an energy source (51). Similarly, Yousif *et al.* (52) observed low TG levels in Sudanese camels during summer, with the highest levels in autumn, reflecting regional dietary cycles. Cholesterol levels followed a distinct seasonal pattern, with peak values in summer, followed by a decrease. These results are consistent with those of Aichouni *et al.* (50), who linked the summer rise in cholesterol to heat stress and reduced feed intake, leading to shifts in lipid metabolism. The lowest LDL levels were recorded in spring (26.33 mg/dl), and the highest in autumn. These fluctuations differ from those observed in cattle, where higher LDL levels are noted during colder months due to increased hepatic lipid synthesis (53). In Damascus goats, however, severe heat stress reduced LDL levels, supporting the idea that thermal stress can influence lipid mobilization and metabolic efficiency (54). HDL levels peaked in summer and autumn, with declines in winter and spring. These results align with those of Abdul-Rahaman *et al.* (55): the highest VLDL values were recorded in spring and winter, and the lowest in autumn and summer. This seasonal trend indicates increased hepatic lipid transport during colder months, consistent with findings in Sudanese camels, where VLDL levels were higher in winter due to greater energy demands (52).

The strong positive correlation between protein and fat underscores their tightly coupled synthesis in the mammary gland. This aligns with findings by Faraz *et al.* (17). Such a high correlation likely reflects shared metabolic pathways, particularly during energy-intensive periods like early lactation, as described by Rudolph *et al.* (27). Triglycerides exhibited strong positive correlations with both protein and fat, highlighting the crucial role of TG in milk fat synthesis. These results are consistent with Patel *et al.* (23), who identified lipid mobilization as a key factor influencing milk quality and composition. The strong negative correlations among lactose, protein, and fat suggest a metabolic trade-off in their synthesis. This inverse relationship has been observed in other studies, such as Khalifa & Zakaria (18). This may be due to redistribution of metabolic resources. Additionally, the dilution effect, where peak milk yield reduces lactose concentration, as discussed by Chamekh *et al.* (15), could also contribute to this negative correlation.

LDL exhibited moderate positive correlations with both protein and fat, suggesting that LDL plays a role in providing precursors for milk synthesis. This is consistent with the observations by Kurpińska *et al.* (56), who found that LDL levels fluctuate in response to lactation demands. HDL showed weaker positive correlations with milk components, indicating a less direct involvement in milk synthesis, as reported by Mohebbi-Fani *et al.* (28).

The negative correlations between VLDL and both protein and fat suggest a distinct lipid transport mechanism compared to LDL and HDL. This contrasts with the positive correlations observed for LDL and HDL, indicating that VLDL may be involved in a different pathway of lipid mobilization and utilization, as discussed by Ahmadpour *et al.* (31). The relatively weak correlations between saturated (SFA), monounsaturated (MUSFA), polyunsaturated (PUSFA), and total unsaturated fatty acids (USFA) with milk yield and composition suggest that fatty acid metabolism operates independently of overall milk synthesis. However, the strong correlation between MUSFA and USFA points to a coordinated regulation of unsaturated fatty acid synthesis, as noted by Konuspayeva *et al.* (57). Moderate positive correlations were observed between milk yield and both protein and fat, indicating that increased milk production is associated with stable concentrations of these components rather than dilution effects (58). This finding aligns with the study by Elhassan & Zubeir (24), who suggested that both physiological and environmental factors influence milk yield and composition, with higher yields often maintaining stable nutrient levels.

Conclusion

This study shows that both lactation stage and season have a clear impact on milk production and the health of dairy camels in Basrah. As camels progress through different lactation stages, their milk production and quality shift, and their bodies adjust to these changes. We also found that the time of year matters-autumn seems to be the best season for milk production, while spring is less favorable. These insights can help farmers better manage feeding and care routines to support healthier camels and more consistent milk yields year-round.

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Conflict of interest

There is no conflict of interest.

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التغيرات الفسيولوجية والكيموحيوية في إنتاج الحليب ومكوناته ومستوى دهون الدم في مراحل الحليب للإبل العراقية

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الخلاصة

تهدف هذه الدراسة إلى التحقيق في تأثير مراحل الإدرار والتغيرات الموسمية على إنتاج الحليب، وتركيبه، والمعايير البيوكيميائية في الدم، وتركيب الأحماض الدهنية لدى الحيوانات الحلوب التي تربى في الظروف البيئية لمحافظة البصرة. تم متابعة ٦٠ حيوانًا بين شهري أغسطس ٢٠١٨ وأبريل ٢٠١٩. تم تحليل عينات الحليب لتحديد نسبة الدهن، والبروتين، واللاكتوز، والمواد الصلبة الكلية، وتركيب الأحماض الدهنية. كما جُمعت عينات دم لقياس تركيز الدهون الثلاثية، والكوليسترول الكلي، وأنواع البروتينات الدهنية، بما في ذلك البروتين الدهني منخفض الكثافة، وعالي الكثافة، ومنخفض الكثافة جدًا. أظهرت النتائج انخفاضًا معنويًا في إنتاج الحليب من بداية الإدرار ٢,٦٩ ± ٠,٢٢ كغ إلى نهايته ٢,٥٠ ± ٠,٢٤ كغ. كما زادت نسبة اللاكتوز تدريجيًا، في حين انخفضت نسب الدهون والبروتين مع تقدم مراحل الإدرار. وسُجّلت

انخفاضات معنوية في الدهون الثلاثية، والكوليسترول الكلي، وجميع أنواع البروتينات الدهنية مع تقدم الإدرار. أما تحليل الأحماض الدهنية، فقد أظهر تغيرات نوعية، حيث ارتفعت نسبة حمض الكابريك خلال منتصف الإدرار، وتذبذبت نسبة حمض اللوريك، بينما ازدادت نسبة حمض البالميتيك في نهاية الإدرار .أما من ناحية التغيرات الموسمية، فقد سُجّل أعلى إنتاج للحليب في فصل الخريف، وأدناه في الربيع. وارتفعت مستويات اللاكتوز بشكل معنوي عبر الفصول، بينما انخفضت نسب الدهون والبروتين. كان أعلى تركيز للكوليسترول الكلي في الصيف، وانخفض بشكل ملحوظ نحو فصل الربيع. وأظهر تحليل الارتباط وجود علاقات قوية بين مكونات الحليب، خصوصًا بين البروتين والدهن، وعلاقة عكسية ملحوظة بين اللاكتوز والبروتين الدهني منخفض الكثافة . في الختام، تؤثر مرحلة الإدرار والتغيرات الموسمية على إنتاج الحليب، وتركيبه، وعمليات أيض الدهون، وتركيب الأحماض الدهنية، مما يعكس تكيفات فسيولوجية لدى الجمال الحلوب.