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Seasonal changes in the yield and composition of camel milk in Mongolia

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This study investigates seasonal variations in the yield and composition of Bactrian camel milk under Mongolia's extensive pastoral systems. Milk samples were collected from 278 lactating camels across ten provinces at 16 time points spanning 30–480 days in milk (DIM). Analyses included fat, protein, lactose, solids-not-fat (SNF), and somatic cell count (SCC). Interviews with 28 camel owning households indicated that milking typically begins between July and September and continues for up to a year, influenced by household labor availability and market access. Results revealed distinct seasonal patterns: peak milk yield (~2.0 L/day) occurred during summer and early autumn (120–240 DIM), possibly reflecting generally more favorable grazing conditions. In contrast, fat and SNF contents increased markedly in winter, while protein followed similar trends. Lactose was higher in summer and autumn. SCC remained stable through mid-lactation but rose toward late lactation. These findings highlight the resilience of Mongolia's camel based pastoral systems and emphasize the importance of supporting herders through improved forage planning and market opportunities to sustain milk production year round.

KEYWORDS

Bactrian camel, camel milk, lactation, seasonal variation, fat content

Introduction

Mongolia's harsh continental climate, characterized by long, cold winters and short growing seasons, places substantial pressure on livestock production. Among domestic animals, Bactrian camels (*Camelus bactrianus*) are uniquely adapted to these extreme conditions and play a vital role in sustaining the livelihoods of pastoral communities. They provide meat, wool, transportation, and most importantly, milk a critical nutritional resource especially during periods when other livestock cease lactation. Bactrian camel milk is widely recognized for its distinct composition, high nutritional value, and health-promoting properties (Khan et al., 2016; Konuspayeva and Faye, 2021; Seifu, 2022). Compared to dromedaries, Bactrian camels produce milk with higher fat content and notable levels of vitamin C, calcium, and phosphorus (Ereifej et al., 2011; Faye et al., 2008; Konuspayeva et al., 2009). However, more than 95% of the global camel population comprises dromedaries (Sikkema et al., 2019), with most research and intensive dairy development focused on Africa and the Middle East (Singh et al., 2017). In contrast, studies on Bactrian camels under traditional pastoral systems in Central Asia remain limited. Camel milk composition is influenced by multiple factors, including genetics, stage of lactation, feeding practices, seasonal forage availability, and reproductive status (Liu et al., 2023; Seifu, 2023). The lactation period in Bactrian camels typically ranges from 9 to 18 months (Arain et al., 2024; Musaad et al., 2013; Oselu et al., 2022), with milk yield and composition expected to fluctuate accordingly. Previous studies from Mongolia, Kazakhstan, and China have reported on the chemical composition of Bactrian camel milk (He et al., 2019; Konuspayeva et al., 2009; Miao et al., 2023), yet few have comprehensively examined how these parameters vary across an entire extended lactation under natural grazing conditions. Given the economic and nutritional importance of camels in Mongolia where camel-derived products can account for over 50% of household cash income in key herding regions (Bolormaa et al., 2025) understanding seasonal trends in milk yield and quality is essential. Such knowledge can inform improved management strategies to sustain milk supply throughout the year, particularly during the critical winter months.

Therefore, this study aims to investigate the seasonal changes in the yield and chemical composition of Bactrian camel milk over a full lactation cycle within Mongolia's extensive pastoral systems. By doing so, it seeks to fill a notable gap in the literature and provide practical insights to support the resilience and economic viability of traditional camel herding.

Materials and methods

Sample collection

Milk samples were collected from lactating camels at different days in milk (DIM) across ten provinces known for high camel densities and traditional milk use. These included Umnugobi, Dundgobi, Bayankhongor, Bayan-Ulgii, Uvs, Zavkhan, Gobi-Altai, Dornogobi, Khovd, and Uvurkhangai. The study involved 278 camels aged 4–15 years, all from traditional pastoral herds. Sampling was carried out at 16 time points from day 30 to day 480 of lactation, roughly at one-month intervals. The first samples at 30 days were collected in April, and the last at 480 days in July of the following year. Camels were not grouped by parity or production stage, which may have contributed to variability in milk yield and composition.

Interviews on Camel milking practices

To complement the milk sampling, semi-structured interviews were conducted with camel-owning households to document traditional milking practices. A total of 28 households were surveyed across the same provinces where milk samples were collected. Figure 1 shows the geographic distribution of these interview sites, which represent key camel-rearing areas across diverse ecological zones.

As described by Undarmaa et al. (2022), the regions where samples were collected (Figure 1) have soft, saline-rich soils and a wide variety of natural vegetation. These conditions support camel grazing throughout the year. During summer and autumn, Bactrian camels mainly graze on pastures dominated by species such as *Stipagrostis gobica*, *Allium mongolicum*, and *Anabasis brevifolia*. In some areas, *Stipa glareosa*, *Cleistogenes species*, and *Salsola passerina* also make up a significant part of the diet. In winter and spring, grazing shifts to more arid and cold-tolerant plants, including *Haloxylon ammodendron, Artemisia species, Kochia prostrata,* and *Nitraria sibirica*.

Milk yield and composition analysis

Milk yield was measured using a graduated cylinder during traditional hand milking. Each session was stimulated by allowing the calf to suckle briefly beforehand. Milk was collected twice daily, and the average daily yield was calculated from these two milkings. Milk samples were analyzed for fat, protein, and lactose content using a mid-infrared automatic analyzer (MilkoScan Minor; Foss, Denmark). Fat content was cross-validated according to ISO 19662:2018 to ensure analytical accuracy. The annual milk yield was estimated using the Test Interval Method described by Sargent et al. (1968), based on interpolated test-day yields across the lactation period. Solids-not-fat (SNF) content was calculated by summing protein and lactose concentrations, following established protocols for camel milk (Faye and Konuspayeva, 2012). Somatic cell count (SCC) was determined using the direct microscopic method described by (Sarikaya and Bruckmaier, 2006). Briefly, 50 mL of gently mixed milk was centrifuged at 1,500 × g for 30 min at 4°C. After removing the upper fat layer and discarding the supernatant, the cell pellet was resuspended in 5 mL of ice-cold phosphate-buffered saline (PBS, pH 7.5). The volume was adjusted to 50 mL with PBS and centrifuged again at 460 × g for 30 min at 4°C. The

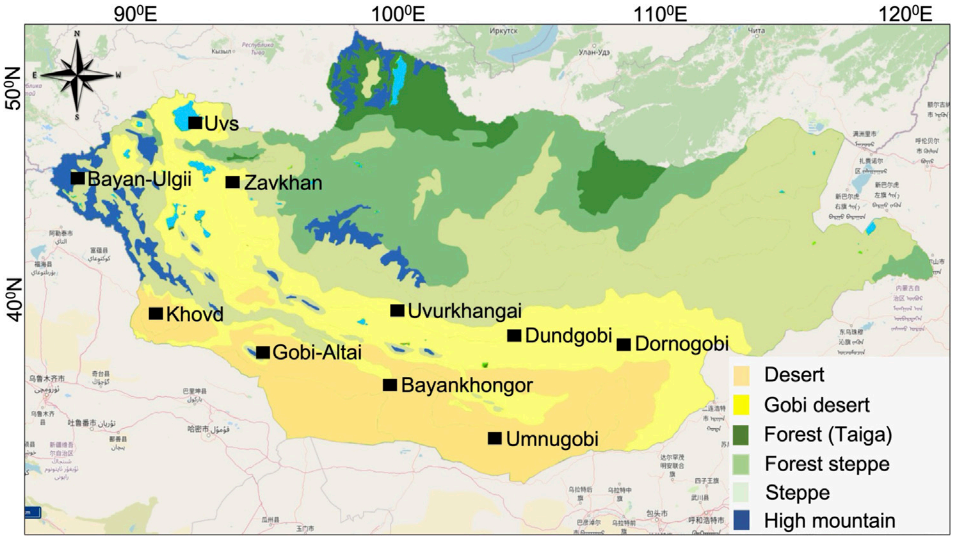

FIGURE 1
Geographic distribution of milk sampling and interview locations across ecological zones. The base map was obtained from the official Mongolian geoportal (https://www.nsdi.gov.mn). Ecological zoning information was adopted from (Oyuntsetseg et al., 2022).

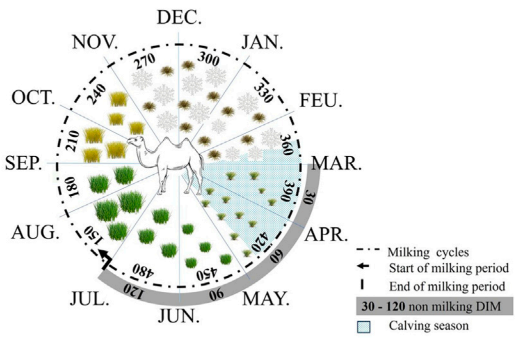

FIGURE 2
The camel milking period across calendar months and seasons. The seasonal categories were based on Bat-Oyun et al. (2015), with May–August classified as summer, September–October as autumn, November–February as winter, and March–April as spring.

resulting pellet was resuspended in 5 mL PBS for staining. Somatic cells were stained using Newman's method and counted under a light microscope at ×200 magnification by enumerating cells in 20 randomly selected fields.

Statistical analysis

Data were analyzed using JMP software (SAS Institute, USA). One-way ANOVA was tested for seasonal effects, followed by Tukey's HSD *post hoc* test. Statistical significance was set at $p < 0.05$. Trends were visualized using Microsoft Excel.

Results and discussion

The camel milking practice

The lactation period of the Bactrian camel is approximately 480 days, or about 16 months (Bolormaa et al., 2025). Interviews with camel owners confirmed that this period runs through different calendar months and seasons. Figure 2 illustrates the traditional camel milking cycle within a year, showing how it progresses through the seasons.

The milking period for camels typically begins between July and September. Its start depends on the region's climate, that year's weather conditions, and the household's available manpower and market access. Since these families move seasonally across vast grazing areas to follow pasture availability, the number of people present in the household at any given time is critical. In addition, households located in remote areas with limited roads and infrastructure often have fewer opportunities to sell camel milk or dairy products. Together, these factors contribute to substantial regional and household level variability in the duration and continuity of camel milking within Mongolia's traditional pastoral systems. If milking begins in July, the milking period will last for a full year, or 12 months, until the same period (July) of the following year. This way, the camel is milked throughout the year until the calf reaches the age of two, around February to March of the following year. From then on, the camel is referred to as a camel with a yearling calf and continues to be milked. However, during the first four months after calving (from calving until the start of milking), they are not milked

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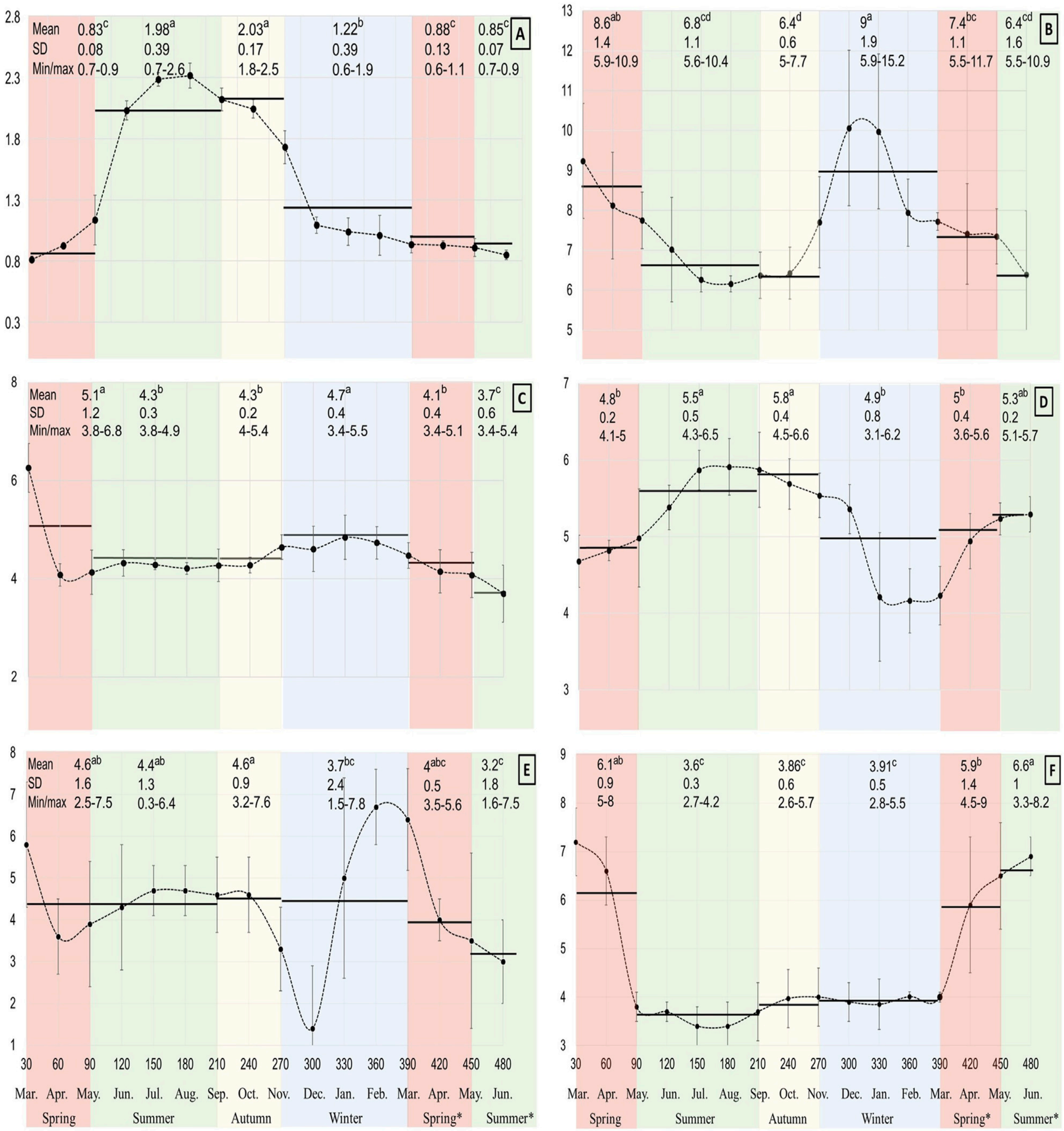

FIGURE 3
Seasonal changes in milk yield and composition of Mongolian Bactrian camels over a 480-day lactation period. **(A)** Milk yield (kg/day), **(B)** Fat (%), **(C)** Protein (%), **(D)** Lactose (%), **(E)** Solids-not-fat (SNF, %), and **(F)** Somatic cell count (SCC $\times 10^5$/mL). *Consecutive seasons through which lactation continues. Different superscript letters indicate statistically significant differences between seasons ($P < 0.001$, ANOVA with Tukey's *post hoc* test).

routinely. To promote the healthy and safe growth of newborn calves, they are kept near the camp, occasionally tethered, and gradually acclimatized to human interaction. During the early summer months (late May to early June), after the mothers are sheared, the calves are allowed to graze freely with their dams until the start of the milking period. The interview result indicates that the milking period of one full cycle covers the camel's 150th-480th DIM, from the entire lactation period.

Milk yield across lactation

The changes in the milk yield and composition during the lactation period (16 months), which lasts across six seasons (Figure 3).

Daily milk yield was around 0.8 L during the 30th-90th DIM after calving (spring), then rapidly increased to approximately 2 L during the 120th-240th DIM (summer, autumn), reaching its peak. Afterward, it decreased sharply to about 1.2 L during the 270th-390th DIM (winter) and continued to decline, reaching around 0.8 L during the 390th-480th DIM (spring, summer), which is similar to the yield at the early stage of lactation. The peak yield occurred during the 120th-240th DIM aligns with the results of Musaad et al. (2013), who noted that the peak yield period of camel milk occurs during the 5th-8th months of lactation. Moreover, the curve showing changes in yield, characterized by a rapid increase to the peak yield period followed by a sharp decline, reflects the seasonal influence. Peak milk yield was observed during the summer months, which may reflect the mostly better grazing conditions typical of this period. The subsequent decline from October to November could be associated with seasonal changes that potentially reduce forage availability under pasture-based systems. However, these interpretations remain speculative, as direct measurements of pasture productivity were not conducted in this study. Musaad et al. (2013) highlighted that camel age and parity have a significant correlation with milk yield, however, in this study, these factors were not accounted for, as camels aged 4–15 years were included without differentiation, making comparison unfeasible.

Changes in fat, protein, and lactose

The fat content of milk varied across different lactation stages and seasons. During the 30th to 90th day in milk (DIM), corresponding to spring, the average fat content was 8.6%. This gradually declined to 6.4%–6.8% between the 90th and 270th DIM, coinciding with the summer and autumn months. A notable increase was observed during the 270th–390th DIM in winter, with fat content peaking at approximately 9%, comparable to levels in early lactation. Thereafter, the fat content declined to around 7.4% during the 390th–450th DIM (spring*) and further decreased to 6.4% during the 450th–480th DIM (summer*), reaching values similar to the previous spring and summer periods. The highest seasonal fat content, ranging from 7.2% to 15.19%, was recorded during winter, which coincides with the typical estrous and conception period in Bactrian female camels (Bolormaa et al., 2025). Additional interview data on the influence of reproductive status during this period revealed that camels in estrus had a significantly higher milk fat content (13.1%) compared to those not in estrus (7.6%). This seasonal rise in milk fat content may be partially influenced by physiological and hormonal changes associated with the estrous cycle. Sodnompil et al. (2023) demonstrated that during the winter breeding season, Bactrian female camels show significant increases in circulating reproductive hormones, particularly estrogen, luteinizing hormone, and follicle-stimulating hormone, especially following estrus synchronization with a GnRH and $PGF_2\alpha$ protocol. These hormonal shifts reflect the animal's physiological readiness for reproduction and align with the seasonal pattern of increased milk fat content observed in this study. Although (Sodnompil et al. (2023) did not measure milk yield or composition, the documented hormonal changes suggest a potential link between reproductive endocrine status and lactational performance. In mammalian species, estrogen and luteinizing hormone are known to influence the secretion of prolactin, a hormone central to mammary gland development and milk synthesis. While this biological mechanism is plausible in camels, it remains hypothetical in the absence of direct data on mammary hormone receptors, prolactin levels, or milk synthesis pathways in Bactrian camels. Therefore, while the observed association between winter estrus and elevated milk fat content is noteworthy, it should be interpreted as correlative rather than causal. Further studies are needed to directly assess hormonal influences on milk production and composition in this species.

The general pattern of changes in milk protein content paralleled that of fat content. Although there was no statistical difference compared to winter (270th-390th DIM), the highest protein content was recorded during the early stage of lactation (30th-90th DIM, spring). The changing pattern in milk lactose content was quite opposite to that of fat and protein. While the milk yield, fat, protein, and lactose content of Bactrian camels have been determined in Mongolia (He et al., 2019; Indra, 2012), Kazakhstan (Konuspayeva et al., 2009), and China (Miao et al., 2023), the studies did not cover the entire lactation period. Information regarding camel lactation is limited, and a unique pattern can emerge when considering the lactation period of up to 480 days, crossing the spring and fall of the following year in this study.

Seasonal variation in SNF and SCC

In addition to the primary macronutrients, seasonal variations in SNF and SCC were also evaluated over the 480-day lactation period (Figure 2). The SNF content, which includes protein, lactose, and mineral constituents, exhibited a marked increase during the winter months. This rise is likely due to the concentration effect associated with reduced milk volume in response to cold stress and limited forage availability. Similar findings have been reported by Faye and Konuspayeva (2012) and (Miao et al., 2023), who observed increases in SNF in camel milk during nutritionally restrictive periods. Konuspayeva et al. (2009) also noted seasonal effects on dry matter and SNF in Bactrian and dromedary camel milk, with higher concentrations recorded during dry or cold seasons. This pattern is consistent with the physiological adaptation of camels to maintain milk nutrient density during challenging environmental conditions.

SCC levels were elevated during the early and late stages of lactation, while remaining relatively stable between 90 and 390 days in milk (DIM), ranging from 3.6 to 3.91 × 10^5 cells/mL. A significant increase was observed toward the end of lactation, with peak values occurring during late winter and early spring (390–480 DIM). Elevated SCC is a well-documented characteristic of camel milk, particularly in the late stages of lactation, even in the absence of clinical signs of mastitis. This pattern has been consistently reported across multiple studies, including which by Nagy et al. (2013), who demonstrated that elevated SCC in camels often reflects normal physiological changes, such as mammary gland remodeling or involution, rather than pathological inflammation. Furthermore, various extrinsic and intrinsic factors have been shown to influence SCC in camelids. Alhussien and Dang (2018) observed that lactation stage, parity, environmental conditions, and milking hygiene practices can all contribute to fluctuations in SCC. Abdel-Hakeem et al. (2025) also highlighted that seasonal stressors, particularly cold exposure and nutritional deficits during winter, may exacerbate immune cell infiltration into milk.

The annual milk yield of Bactrian camels over the 150th to 480th day in milk (DIM) was estimated at approximately 543 kg by the Test Interval Method (Sargent et al., 1968). Seasonally, the distribution of milk production was as follows: summer (24%), autumn (23%), and winter (29%), with the remaining 24% produced during the spring and early summer months of the following year. These proportions highlight the dominance of the early to mid-lactation stages in total milk output under Mongolia's extensive, pasture-based camel husbandry system.

From mid-summer to late winter (July to February), corresponding to 150–360 DIM, camels produced approximately 76% of the annual milk yield, while the remaining 24% was obtained during 360–480 DIM, spanning spring to early summer (March to June). This lactation pattern is particularly significant in the context of Mongolia's harsh continental climate and traditional animal husbandry practices. During the winter months (November to February), sheep and goats typically cease milk production, and cattle enter late lactation with substantially reduced yields. In contrast, camel milk production not only continues during winter but peaks, accounting for the highest seasonal contribution (29%). This characteristic underscore the camel's critical nutritional and economic value to owning households during periods when other milk sources are scarce.

Despite this importance, systematic research on the lactation performance of Mongolian Bactrian camels remains limited. Early data by Luvsan (1975) estimated an average annual yield of around 600 L, while Buyankhishig (2011) reported that, excluding the portion consumed by calves, a camel could yield approximately 365.7 L annually. More recently, Zarrin et al. (2020) reported average yields of 300 kg per year in Mongolia, which is considerably lower than the 645 kg reported in China and 850–1700 kg in Kazakhstan. These disparities likely reflect differences in management systems, and environmental conditions. Supporting this, Singh et al. (2017) found that Bactrian camels typically produce less milk than dromedaries, with daily outputs averaging 0.5 L. Similarly, Zhao et al. (2015) documented daily yields ranging from 0.5 to 2.0 L in China, excluding the calf's portion, which closely aligns with the present study's estimates of both daily and cumulative yields in Mongolia.

Conclusion

This study revealed distinct seasonal variations in the yield and composition of Bactrian camel milk under Mongolia's extensive grazing systems, with peak milk production aligning with summer pastures and elevated fat and SNF levels occurring during the winter breeding season. Importantly, camels continue to provide milk even when other livestock typically cease lactation, highlighting their critical role in sustaining rural dairy supply during Mongolia's harsh winters.

From a practical standpoint, these findings suggest that improving strategic pasture management, such as conserving high-quality forage for late lactation and winter months, could help maintain milk yield and quality throughout the extended lactation period. Additionally, targeted supplemental feeding during winter and early spring may stabilize milk composition and support camel health during periods of nutritional stress. Promoting such adaptive practices will enhance the economic viability of camel herding, reinforce household food security, and further strengthen the resilience of Mongolia's traditional pastoral systems.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

This research was approved by the Ethical Committee of Veterinary Science and Bio-Medical Research of the Mongolian University of Life Sciences (approval no. 24/01-07). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

Methodology: BT and N-OP; Interview: BT and GS; Formal Analysis: BT and N-OP; Supervision: N-OP; Original Draft: BT and N-OP; Review and Editing: N-OP; Sampling: BT, N-OP, TS, GS, and HM. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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