THESES OF DOCTORAL (PhD) DISSERTATION

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ENDOGENOUS AND EXOGENOUS FACTORS AFFECTING THE COMPOSITION OF RAW CAMEL'S (*Camelus dromedarius*) MILK

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1 INTRODUCTION AND AIMS

The world's annual camel milk production increased from 0.63 million tons in 1961 to approximately 2.9 million tons in 2013 (FAO, 2017), which is a 4.6-fold increase in production over a 50-year period. With this quantity, camels are the fifth most important dairy animals following cattle, water buffalo, goat, and sheep (Faye and Bonnet, 2012). Although the composition of dromedary camel milk was described in many previous publications and has recently been summarized by several authors (Konuspayeva et al., 2009; Al haj and Al Kanhal, 2010; Fábri et al., 2014), systematic, long-term studies have not yet been conducted on this species.

Mean dromedary camel milk fat, protein, lactose, and total solids (TS) contents were reported to be 3.5 to 3.8, 3.1 to 3.35, 4.4 to 4.57, and 11.9 to 12.47%, respectively (Konuspayeva et al., 2009; Al haj and Al Kanhal, 2010). However, literature data show a wide range of variation, and the results of different studies are difficult to compare because of the differences in environmental and physiological conditions, breed, year, and methodology.

The objectives of our study were (1) to monitor the chemical composition of regularly collected individual milk samples over several years at the world's first large-scale dairy camel farm, (2) to provide solid reference values for dromedary camel milk composition, and (3) to determine the most important genetic and nongenetic factors affecting milk composition under intensive management.

2 MATERIALS AND METHODS

The study was conducted at the premises of Emirates Industry for Camel Milk and Products, the world's first large-scale dairy camel farm located in Dubai, United Arab Emirates, from May 2009 through December 2013. A total of 1,528 lactating dromedary camels were included in the study, and the number of animals milked daily ranged from 421 to 828 during this time. The animals belonging to different breeds or ecotypes were between 5 to 19 years of age and had variable parity.

Dromedaries were milked twice a day with an automatic system in a 2 × 12 herringbone milking parlor. Milk yield (kg) of individual dromedaries was measured during each milking with a milk meter approved by the International Committee for Animal Recording (ICAR). Data were collected by herd management software (Nagy et al., 2013a,b). As part of the herd health and milk quality-monitoring program, milk samples from individual dromedaries were collected approximately at monthly intervals during lactation.

The gross chemical composition [i.e., fat, protein, lactose, TS, and solids-not-fat (SNF) concentrations] of raw camel milk was determined with an automatic milk analyzer (MilkoScan FT 120; Foss A/S, Hillerød, Denmark). The following parameters were recorded for each milk sample: animal, date, year, month of the year, days postpartum (dPP) and month postpartum (mPP), parity, breed or ecotype, calf sex, and daily morning milk yield (kg). The mPP was calculated from dPP using the formula mPP = round (dPP/30 + 0.49). Due to lack of complete history, parity was defined as either first delivery (primiparous) or more than 1 deliveries (multiparous). Based on geographical origin, color, appearance, and body conformation, dromedaries were categorized into the following well-

distinguishable breeds or ecotypes: Emirati, Emirati-cross, Black, Pakistani, Saudi, Saudi-cross, and Sudanese.

The effects of parity, breed or ecotype, calf sex, stage of lactation (mPP), season (month of the year), and year were tested by t-test and linear mixed models with Tukey's test for pairwise comparisons using the R statistical package (R Foundation for Statistical Computing, Vienna, Austria). The effect of parity was evaluated by t-test, and then the samples of primiparous dromedaries were excluded from further analysis. Breed effect was tested on several subsets of data by linear mixed models. First, we compared all breeds or ecotypes in 2013 and then omitted the year 2009 and the Pakistani breed or ecotype. In this study, only the analysis on data from 2013 is presented. In that particular year, samples were collected from all 7 ecotypes and the linear mixed model included breed or ecotype, month, and breed × month interaction as fixed factors and mPP as a random factor. The effects of season (month of the year), stage of lactation (mPP), season × stage of lactation, and sex were tested by mixed linear model with breed and year as random factors. The effect of year was evaluated by a linear mixed model including 4 breeds or ecotypes (Emirati, Emirati-cross, Saudi, and Saudi-cross) that occurred in each study year with month and mPP as random factors.

3 RESULTS

During the study, a total of 18,158 milk samples were collected on 963 test days. Samples with incomplete production parameters or from milk yield below 1 kg were omitted. Therefore, 16,851 samples taken on 955 test days (mean ± SD; 17.6 ± 8.1 samples/d) from 1,528 dromedaries (11.0 ± 6.8 samples/animal) were included in the final analysis. The overall mean (±SEM) daily yield and fat, protein, lactose, SNF, and TS concentrations of the morning milk were 4.00 ± 0.012 kg, 2.58 ± 0.007%, 2.95 ± 0.004%, 4.19 ± 0.004%, 8.08 ± 0.006%, and 10.46 ± 0.01%, respectively, throughout the study. The daily mean (±SEM) fat, protein, lactose, SNF, and TS contents of the morning milk were 99.7 ± 0.33, 116.1 ± 0.33, 168.4 ± 0.53, 321.7 ± 0.94, and 413.9 ± 1.18 g, respectively Morning milk yield (kg/d) showed a positive correlation with lactose (%) and a negative correlation with all other components tested. Fat and lactose percentages correlated negatively with each other; however, the relationship between any other pairs of milk components was positive.

3.1 Effect of Parity

The number and percentage of milk samples (n = 318; 1.9%) from primiparous animals (n = 60; 3.9%) was low compared with those from multiparous dromedary camels. In addition, the majority of samples from primiparous dromedaries (n = 256; 80.5%) were collected during the final year of the study and breeds or ecotypes were represented disproportionately. Despite the uneven distribution of samples, parity exerted a strong effect ($P < 0.001$) on all morning milk parameters tested. Primiparous animals produced less milk with reduced quantities of fat,

protein, lactose, SNF, and TS than did their multiparous counterparts ($P < 0.001$). However, in terms of chemical composition (i.e., percentages of major chemical components), the milk from primiparous dromedary camels was superior to that from multiparous dromedaries ($P < 0.001$) (**Table 1**).

Table 1 Influence of parity on daily yield, chemical composition, and quantity of major components of morning dromedary camel milk

Parameter	Primiparous (n = 318)	Multiparous (n = 16,533)	Total (n = 16,851)
	Mean ± SEM		
Morning milk yield, kg/d	3.23 ± 0.060[b]	4.01 ± 0.012[a]	4.00 ± 0.012
Chemical composition, % (g/100 ml)			
Fat	2.86 ± 0.059[a]	2.57 ± 0.007[b]	2.58 ± 0.007
Protein	3.14 ± 0.028[a]	2.95 ± 0.004[b]	2.95 ± 0.004
Lactose	4.53 ± 0.029[a]	4.19 ± 0.004[b]	4.19 ± 0.004
SNF	8.54 ± 0.044[a]	8.07 ± 0.006[b]	8.08 ± 0.006
TS	11.10 ± 0.080[a]	10.44 ± 0.010[b]	10.46 ± 0.010
Quantity, g/d			
Fat	90.9 ± 2.17[b]	99.8 ± 0.33[a]	99.7 ± 0.33
Protein	100.6 ± 1.87[b]	116.4 ± 0.33[a]	116.1 ± 0.33
Lactose	146.8 ± 2.91[b]	168.8 ± 0.53[a]	168.4 ± 0.53
SNF	275.3 ± 5.17[b]	322.6 ± 0.95[a]	321.7 ± 0.94
TS	356.6 ± 6.63[b]	415.0 ± 1.19[a]	413.9 ± 1.18

3.2 Effect of Breed

The effect of breed or ecotype was evaluated on several subsets of data. First, we compared all breeds or ecotypes in 2013 and then omitted the year

2009 and the Pakistani breed or ecotype. In the present study only results from 2013 are presented (**Figure 1**). In that particular year, all 7 genotypes contributed and a total of 2,332 milk samples were collected from multiparous dromedaries with a known parturition date. Almost 90% of the samples (n = 2,090; 89.6%) originated from 4 ecotypes (Emirati, Emirati-cross, Saudi, and Saudi-cross). Breed or ecotype had a strong influence on all parameters ($P < 0.01$ for fat percentage and $P < 0.001$ for all other parameters tested). The effect of month of the year was also confirmed; however, no interaction was found between the 2 factors. The stage of lactation was different among breeds or ecotypes ($P < 0.05$). Based on morning milk yield means, dromedary camels could be divided into 3 milk production categories, such as high (>4.2 kg: Emirati-cross, Black, Pakistani), medium (3.8 to 4 kg: Emirati, Saudi-cross), and low (<3.7 kg: Saudi, Sudanese) producing genotypes (**Figure 1**).

Despite being significant, differences in milk composition among breeds were small and inconsistent. Moderate fluctuations of 6.6, 5.9, and 4.1% were observed in mean protein, SNF, and TS concentrations, respectively, whereas, mean fat and lactose levels were markedly different among ecotypes, with differences up to 18.2 and 13.2%, respectively (**Figure 1**).

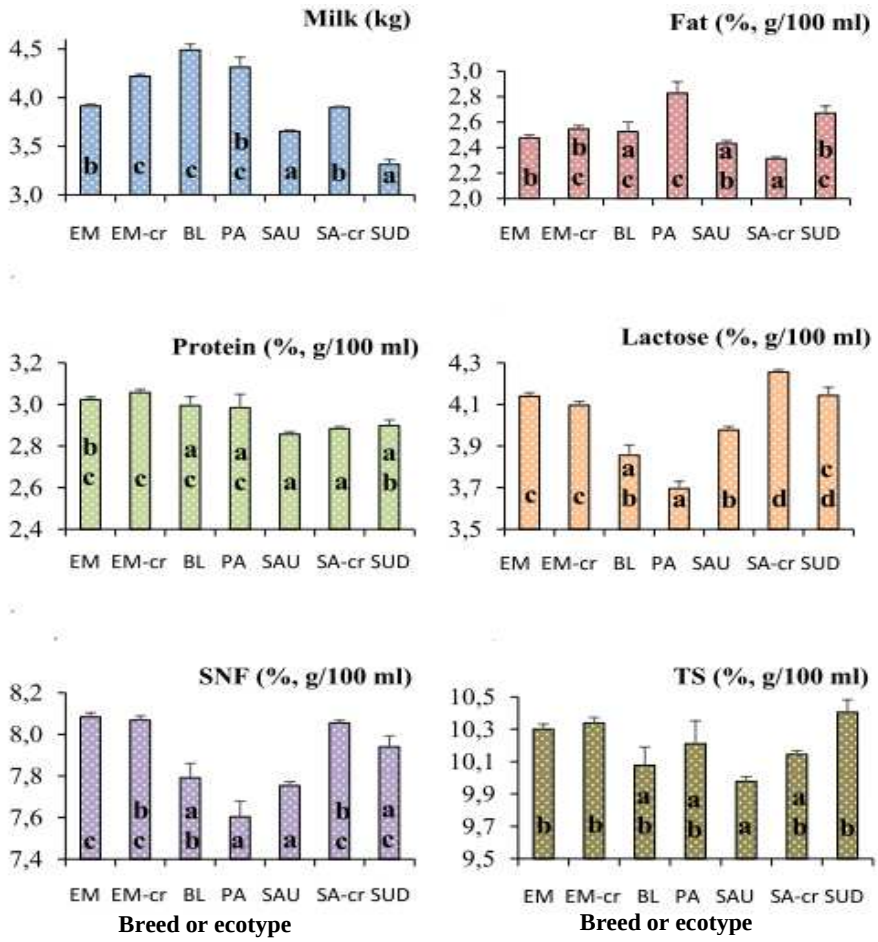

Figure 1 Influence of breed or ecotype (EM = Emirati; EM-cr = Emirati-cross; BL = Black; PA = Pakistani; SAU = Saudi; SA-cr = Saudi-cross; SUD = Sudanese) on mean chemical composition (%, g/100 ml) and daily yield of morning dromedary camel milk (kg). Bars with different letters (a–d) differ ($P < 0.05$).

3.3 Effect of Calf Sex

The effect of sex was tested on 13,854 milk samples. Of these samples, 46.8% (n = 6,487) and 53.2% (n = 7,367) originated from dromedaries raising female and male calves, respectively. The mixed linear model

showed that sex of the calf influenced milk production and some major milk components ($P < 0.05$). Although statistically significant, these differences are not likely to be of biological importance. Average morning milk production of animals with male calves (4.03 ± 0.007 kg/d) was higher ($P < 0.05$) than that of dromedaries raising female calves (3.99 ± 0.008 kg/d). By contrast, lactose and SNF concentrations were higher ($P < 0.05$) in milk from dams with female calves (4.24 ± 0.004 and 8.10 ± 0.004%, respectively) than in milk from dams with male calves (4.23 ± 0.004 and 8.07 ± 0.004%, respectively). However, no difference was observed ($P > 0.05$) in fat, protein, and TS levels (%) of milk samples collected from the 2 groups of dromedaries.

3.4 Effect of Stage of Lactation, Postpartum Changes

Data on dPP were available for 14,085 samples (85.2%) collected from multiparous dromedary camels. Determined by dPP of the last milk sample, the mean length (±SD) of lactation was 439 ± 171 d, but the real length exceeded this. Samples taken after the 23rd month of lactation (>705 dPP) were excluded from the analysis.

The mixed linear model indicated that the stage of lactation strongly influenced ($P < 0.001$) milk yield and all milk components. However, there was also a significant interaction with season (month of the year, $P < 0.001$); therefore, the effect of the 2 factors could not be separated. Mean morning milk yield reached its maximum during the 4th month of lactation at 4.58 ± 0.01 kg/d, and then it decreased slowly until the 8th month, followed by a steady decline throughout the long lactation period (~3.1% per month) to 2.94 ± 0.04 kg/d at 23 mPP. Monthly mean fat, protein, lactose, SNF, and TS concentrations of morning milk showed large fluctuation from 2.0 to 3.8, 2.7

to 3.4, 3.6 to 5.0, 7.5 to 9.1, and 10 to 11.9% throughout lactation, respectively. The concentration of all milk components decreased from 1 to 5 mPP, owing to dilution by increasing milk quantity during this period. Later, lactose concentration continued to decrease in parallel with decreasing milk production. However, the concentration of other components showed a temporary increase in mid-lactation, from 6 to 11 mPP, and 1 year later, from 18 to 23 mPP, resulting in an overall increasing tendency in fat, protein, and TS concentrations throughout lactation.

Changes in quantity of major chemical components of the morning milk showed very different postpartum patterns. Lactose, SNF, and TS contents decreased simultaneously with milk yield, whereas total fat production increased from 6 to 11 mPP, followed by a 6-month decline and an increase again in late lactation. In contrast, protein yield of the morning milk was relatively constant for 1 year, but then it dropped sharply by 15 mPP and remained stable at a lower level for the rest of the lactation period (**Figure 2**).

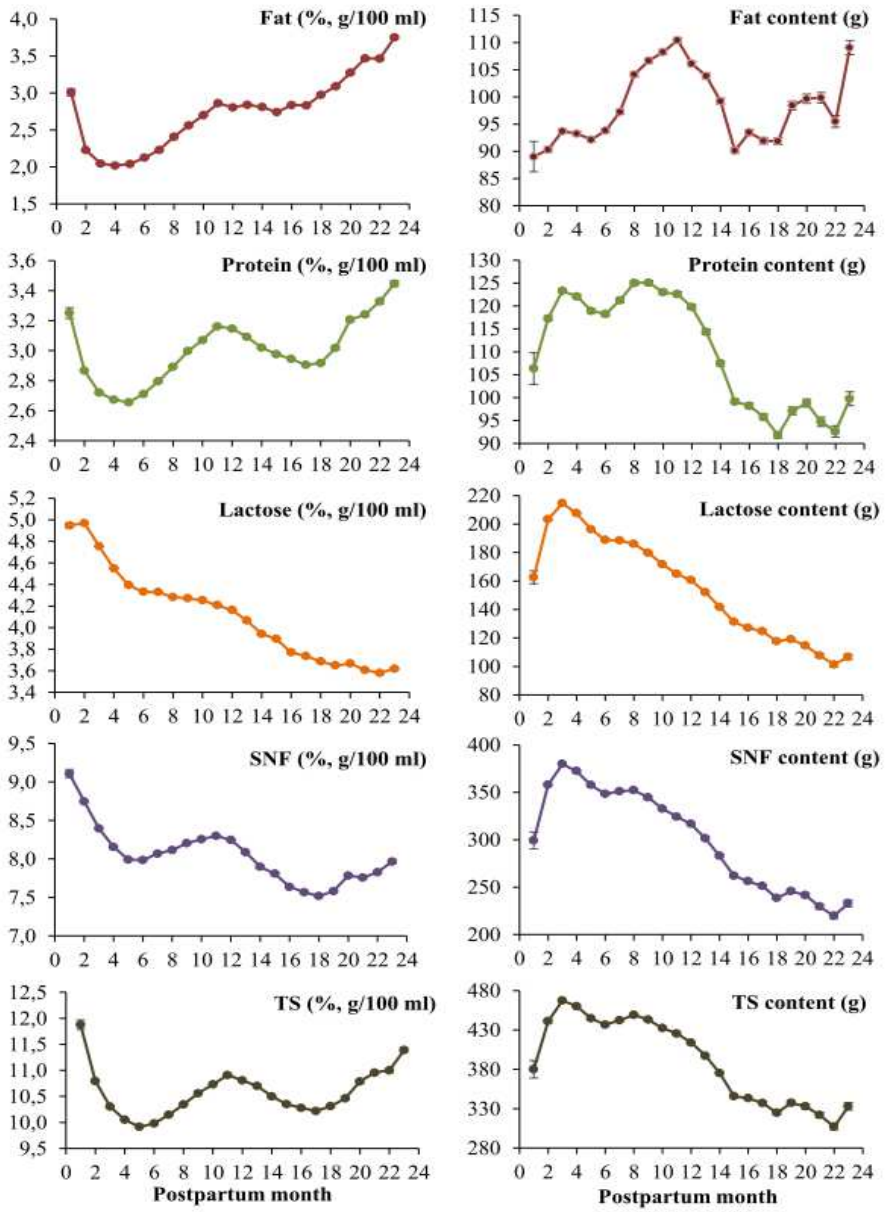

Figure 2 Postpartum changes in monthly mean fat, protein, lactose, SNF, and TS concentrations (%) and contents (g/d) of morning dromedary camel milk.

3.5 Effect of Season, Monthly Changes

As confirmed by the mixed linear model, month of the year exerted a strong effect ($P < 0.001$) on both the yield and the chemical composition of camel milk. In addition, its interaction with the stage of lactation was also significant ($P < 0.001$). Average morning milk yield was at its lowest (3.85 ± 0.02 kg/d) at the beginning of the year, then it increased gradually until July, and peak production was observed in November (4.23 ± 0.02 kg/d). Monthly fluctuations in average milk yield were moderate (< 9%). Monthly changes in mean fat, protein, SNF, and TS concentrations (%) of the morning milk showed the same typical seasonal pattern. The highest values were observed during winter (December and January), whereas the lowest percentages were measured in summer (June and July). At the same time, the lowest mean lactose concentrations were recorded in fall (September and October). The mean fat, protein, lactose, SNF, and TS concentrations ranged from 2.1 to 3.0, 2.7 to 3.3, 4.1 to 4.4, 7.8 to 8.6, and 9.8 to 11.3%, respectively, throughout the year. The extent of seasonal changes was most pronounced for fat concentration (28.7%), followed by protein (19.9%), TS (12.8%), SNF (9.5%), and lactose (5.5%).

As a general rule, changes in mean amounts of fat, protein, SNF, and TS in morning milk followed a seasonal pattern similar to that observed for concentrations. However, SNF and TS contents were not statistically different from January to August and from April to August, respectively. Mean lactose content was relatively stable throughout the year (**Figure 3**).

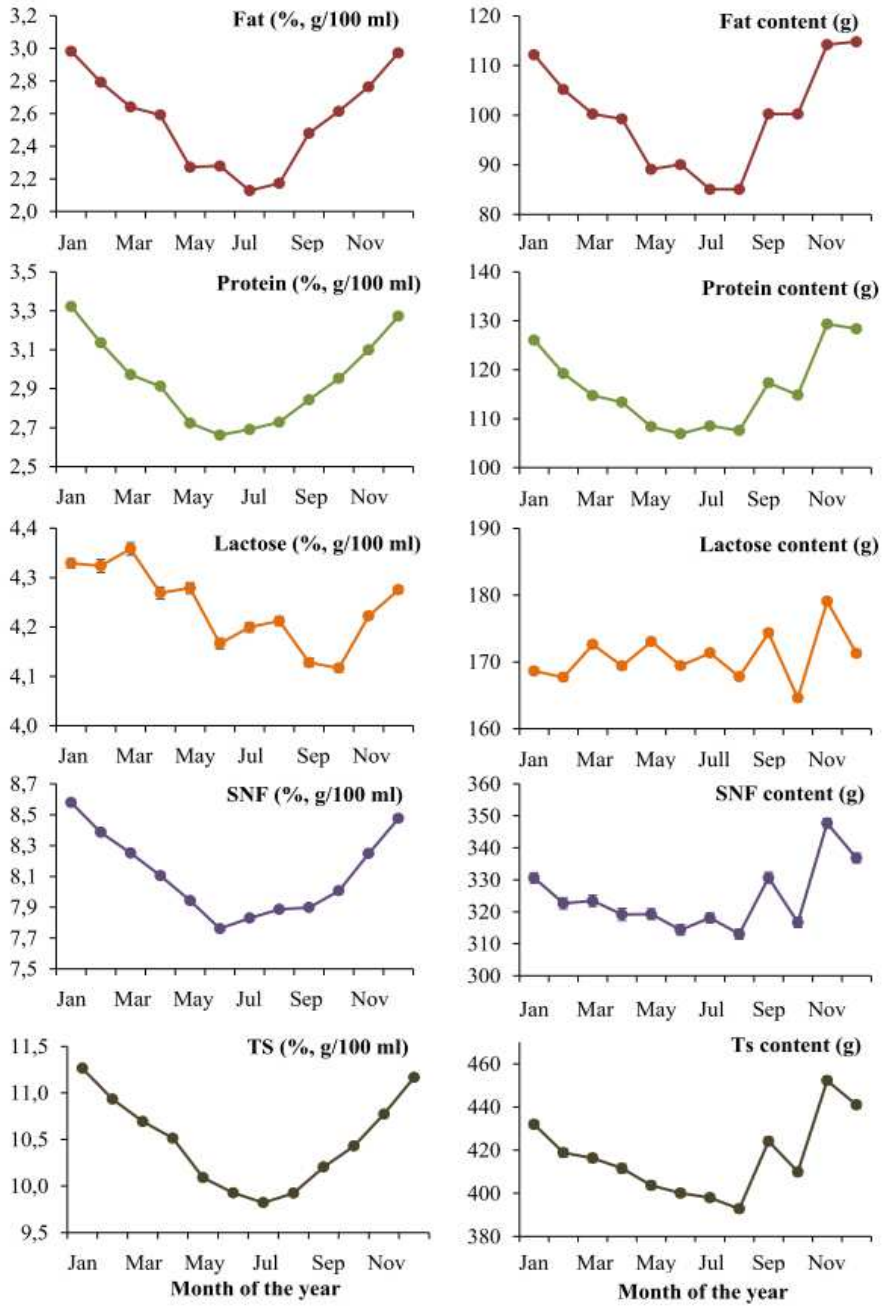

Figure 3 Seasonal changes in monthly mean fat, protein, lactose, SNF, and TS concentrations (%, g/100 ml) and contents (g/d) of morning dromedary camel milk.

3.6 Effect of Year

The effect of year was tested on milk samples collected from multiparous dromedaries belonging to the Emirati, Emirati-cross, Saudi, and Saudi-cross ecotypes. These 4 breeds provided the majority of milk samples evaluated in the present study. Milk yield and the concentrations and amounts of all major chemical components in milk varied among the years ($P < 0.001$), with significant interaction between year and genotype ($P < 0.001$). Average concentrations of major milk components were higher during the middle of the study period (2010 to 2012) than in the first and last years (2009 and 2013). The yearly fluctuation in mean fat, protein, lactose, SNF, and TS concentrations was 8.2, 8.3, 4.1, 5.0, and 4.5%, respectively. The highest quantity of milk components was measured in 2012, corresponding to an increased milk yield in that particular year.

4 NEW SCIENTIFIC FINDINGS

[1] On 963 sampling days, between May 2009 and December 2013, a total of 18,158 individual dromedary milk samples were collected from seven breeds/ecotypes of lactating camels. The mean values for fat, protein, lactose, total solids (TS), and solids-not-fat (SNF) concentrations of the individual dromedary milk samples were as follows: 2.58%, 2.95%, 4.19%, 8.08%, and 10.46%, respectively. These percentages are considerably lower compared with data published earlier.

[2] Based on the most comprehensive database available globally, we have analyzed the effects of major factors influencing the composition and quantity of dromedary milk produced under constant feeding and management conditions. Among the variation factors, parity, stage of lactation and season exerted the most pronounced effect on milk composition (fat, protein, lactose, SNF, and TS) and quantity ($P < 0.001$). Breed/ecotype and year factors had significant but small effect on milk composition (fat, protein, lactose, SNF, and TS) and quantity. We have detected significant ($P < 0.05$), yet small calf gender-biased differences in milk yield and lactose and solids-not-fat contents. The significant level of the breed/ecotype factor on the fat content was $P < 0.01$.

[3] For the first time ever, we have demonstrated significant ($P < 0.05$), though small calf sex-biased differences in milk composition (lactose and SNF contents) and milk yield. We have also proved that milk

composition of primiparous dromedaries significantly differs from that of multiparous camels ($P < 0.001$).

[4] We have provided evidence that despite constant diets and relatively small annual changes in daylight lengths, the monthly changes in mean fat, protein, SNF, and TS percentages of morning dromedary milk show typical seasonal fluctuations. The highest values were observed during winter (December and January), whereas the lowest percentages were measured in summer (June and July). The extent of seasonal changes was most pronounced for fat concentration (28.7%), followed by protein (19.9%), TS (12.8%), and SNF (9.5%). We have hypothesized that seasonal changes in the chemical composition of camel milk may reflect an endogenous circannual biological rhythm.

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[1] Nagy, P., **Fábri, Zs. N.**, Varga, L., Reiczigel, J., Juhász, J. (2017): Effect of genetic and nongenetic factors on chemical composition of individual milk samples from dromedary camels (*Camelus dromedarius*) under intensive management. *Journal of Dairy Science* **100** (11), 8680–8693. ***[IF: 2.474]***

In Hungarian:

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[2] **Fábri, Zs. N.**, Nagy, P., Varga, L. (2014): A tevetej termelése, általános jellemzői, összetétele és egészségre gyakorolt jótékony hatásai. Irodalmi összefoglaló. 2. Tejcukor-, ásványianyag- és vitamintartalom, egészségügyi előnyök (Production, general characteristics, chemical composition and health benefits of camel milk. Literature review. 2. Lactose, minerals and vitamin contents, health benefits). *Magyar Állatorvosok Lapja* **136** (9), 553–557. ***[IF: 0.185]***

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