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PHYSICOCHEMICAL CHARACTERISTICS AND MICROBIOLOGICAL QUALITY OF CAMEL MILK IN TUNISIAN ARID LANDS : A COMPARISON WITH GOAT AND SHEEP MILK

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ABSTRACT

The aim of this study was to compare the physicochemical parameters and the microbiological quality of milk samples of 3 different species in Tunisian arid lands *viz.* camel, goat and sheep. The results for milk characteristics showed significant differences among the 3 species. Camel milk was the the richest in total proteins (38,6 ±0.07 g/l), the highest ash content (8,92 g/l±0,49), the most acid pH (pH 6.40±0.03) and the lowest density (1.02±0.2), whereas sheep milk was characterised by the greatest average value dry matter (151,17±2,60 g/l) and the highest fat content (52±0,55 g/l). Likewise, the microbial quality of camel milk was higher than that of sheep and goat milk based on total counts of coliform (TCC), yeast and molds (Y/M) and lactic bacteria (LAB). Although, the microbial analysis of total mesophilic aerobic bacteria (FMAT) revealed an exceeds of standard criteria, suggesting that all samples may contain higher levels of microbial contaminants. To reduce this contamination, several measures must be taken.

Key words: Arid region, camel, goat, milk quality, sheep, Tunisia

In Tunisia, sheep, goats and camels dominate livestock in the arid pastoral zones of the south (Khaldi *et al,* 2022). These species are vital for providing goods and services such as milk, meat, wool and transportation, making up a key part of the agricultural sector. Raw milk from these animal species has been a subject of interest due to its unique composition and potential health benefits.

The FAO reports that the global milk production is approximately 3.15 million tons of which cow milk represents over 85% with a growing interest in consuming raw milk from other species.

For exemple, camel milk production has notably increased since 1962, growing annually by 7% to reach a worldwide production of 6.6 million tons. This growth rate surpasses that of cow milk twofolds and that of sheep and goat milk threefold (Konuspayeva *et al,* 2022). The global demand for camel milk could be attributed to its diverse bioactive compounds, flavour and potential health benefits (Seifu, 2022; Mahamat Ahmat *et al,* 2023).

Indeed, the production of milk worldwide is influenced by various livestock that plays a crucial role in the livelihoods of many communities in arid regions characterised by extreme heat and limited water resources.

Numerous studies have demonstrated that a variety of variables appear to be significant in influencing the quality of these milk. The animal species (Yasmin *et al,* 2020), milking practices (Atigui *et al,* 2023), animal health and lactation stage (Chamekh *et al,* 2020; Mollica *et al,* 2021), season (Dhaoui *et al,* 2019; Mollica *et al,* 2021) and feeding practices (Mollica *et al,* 2021; Laameche *et al,* 2024) are some examples of these factors.

Physico-chemical properties such as fat, protein, lactose and mineral composition play a crucial role in determining the nutritional quality of milk. Additionally, the microbiological quality of milk is important for assessing its safety and shelf life (Atigui *et al,* 2023).

Understanding the differences and similarities among these different types of milk can provide

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valuable insights into their nutritional value and suitability for human consumption.

By comparing these properties among camel, goat and sheep milk, we can gain a better understanding of their unique characteristics and potential health benefits.

In this study, the focus is on comparing the physico-chemical properties and microbiological quality of raw camel milk with that of goat and sheep milk in Tunisian arid lands.

Materials and Methods

2.1. Biological Material

A total of 32 samples of raw milk were obtained by mixing the milk of several females. Milk was obtained from 3 species : camel milk (*Camelus dromedarius*, n=22), goat (*Capra hircus,* n =5), sheep (*Ovis aries,* n = 5). Camel and goat milk were obtained from herds belonging to the Wildlife and Livestock Laboratory, Arid lands Institute (IRA, Médenine), Tunisia while sheep milk was collected from a farm in the region of Medenine (Southeast of Tunisia).

The milk samples were collected in sterile bottles and then transferred to the laboratory under aseptic conditions.

2.2. Physical and chemical analyses

The physical characterstics of raw milk including density, pH and dornic acidity were measured immediately after arrival of samples at the laboratory. The pH was measured using a digital pH meter (model WTW 422), the dornic acidity was measured by titrimetric method as described by the AOAC International (Latimer, 2016) and the density was determined at 20°C using a lactodensimeter accompanied by a thermometer.

According to the international standard, the dry matter of raw milk was determined by loss on drying at 105°C for 3 hours (IDF, 2010) and the ash content was determined after incineration of the dry matter at 550°C until complete combustion of organic matter (AOAC, 2012). The fat content was determined through acid-butyrometric analysis (IDF, 2009) and the total protein content was determined by the Kjeldahl method (IDF, 2014).

2.3. Microbiological analysis

In order to determine the microbiological quality of raw milk, 1 ml from each sample was taken and then diluted with 9 ml of physiologique water. According to the international standard (ISO, 2020), further decimal dilutions were made from this dilution and plated on appropriate media.

Plate count agar (PCA, Merck, Germany) was used to isolate total aerobic mesophilic bacteria (TMAB). Incubation was performed at 30°C for 72 hrs (ISO, 2013). Sabouraud chloramphenicol (Pronadisa) was used to detect and enumerate yeast and molds (YM). Incubation was carried out at 25°C for 3–5 days (ISO, 2008).

Violet red bile agar (AppliChem) was used to quantitatively detect total coliformes (TCC). Seeding was done in a double layer and the samples were incubated at 30°C for 24 to 48 hours (ISO, 2006).

De Man-Rogosa-Sharpe (MRS) agar (Scharlau Chemie, S.A.) was used to detect and enumerate lactic acid bacteria (LAB).The agar plates were incubated at 30°C for 48 hours to allow the growth of LAB colonies (ISO, 2007).

2.4. Statistical analysis

Statistical analysis was conducted by comparing the averages of different parameters across species being studied. The significant differences between means were determined by one-way analysis of variance ANOVA and followed by the Tukey-Kramer test to correct the P values for multiple comparisons using GraphPad Prism 8.4.3 software package.

Results and Discussion

3.1. Physicochemical properties of raw milk

Results showed the physical characteristics of the milk samples (Table 1). Statistical analysis revealed no significant differences in pH, acidity and density among the three types of milk tested ($p>0.05$).

The pH values for the various samples ranged between 6.6 and 6.48. The pH of camel milk was lower than that of milk from other species. The average pH value of the collected goat milk was in the order of 6.6. This result was in agreement with the findings of Fguiri *et al* (2017). The pH results of camel milk (6.4) and of sheep milk (6.42) showed similair values observed by Singh *et al* (2017).

According to the litterature, milk from small ruminants has a pH range of 6.5 to 6.8 (Khaldi *et al,* 2022) while camel milk has a pH range of 6.2 to 6.5 (Seifu, 2022). The high vitamin C content and the presence of certain organic acids in camel milk contributes to its lower pH (Almoosawi and Almahdawi, 2023).

Additionally, measuring the pH and acidity of milk samples could be a critical indicator of animal health and the hygienic quality of the milk (Gagara *et al*, 2022).

As shown in table 1, sheep milk had the highest dornic acidity values followed by goat milk and then by camel milk with values 19.58, 18.6 and 18.3, respectively. Previous studies (Elbagerma *et al,* 2014; Khaldi *et al,* 2022) have reported differences in the acidity value of goat, sheep and camel milk compared to the current research findings. However, other research have indicated comparable acidity findings. The values of titratable acidity in goat milk were in line with that reported by Otmane *et al (*2022). The titratable acidity values of sheep milk were similar to the findings of Asif (2010) and the values of titratable acidity in camel milk were similar to that reported by El-Hatmi (2015). Indeed, the acidity of milk could be influenced by various factors such as the presence of lactic acid bacteria, temperature, nature of forages and lactation stage (Alaoui *et al,* 2019; Laameche *et al,* 2024).

Table 1. Physical characteristics of camel, goats and sheeps milk in the Tunisian arid land.

Properties	Source of milk		
	Camel	Goat	Sheep
pH	6, 4± 0,3	6,6±0,6	6.48±0.3
Acidity (°D)	18 ,3±1,36	18,6±3,75	19.58±1.12
Density	1.02 ±0.2	1.03 ±0.06	1.04 ±0.05

The value of density obtained of camel milk is lower than those of milk from the other species. This value was ranged from 1.026 to 1.035, similar to previous density camel milk readings, averaging around 1.029 (Seifu, 2022). The density of milk is indeed influenced by various factors. The fat content, total solids and temperture are major factors influencing the density of milk (Parmar *et al,* 2021).

Table 2 shows the chemical composition of camel milk compared with sheep and goat milk. The results of compositional analyses revealed a significant difference among the 3 species (P<0.001).

Compared with goat and sheep milk, camel milk had the highest (P < 0.001) ash (8.92 g/l) and protein contents (38.6 g/l). The present observations are consistent with the finding of Bouhaddaoui *et al* (2019) for Moroccan camel milk and El-Hatmi (2015) for Tunisian camel milk. In contrast to these findings, Yasmin *et al* (2020) and Khaldi *et al* (2022) found that camel milk had the lowest ash and protein content compared to sheep milk and goat milk.

In this respect the diversity of ash content values in camel milk may be influenced by such facors like hydration status of the camel and the stage of lactation (Bouhaddaoui *et al,* 2019). Also, ash content in camel milk could be a good source of minerals in the human diet like sodium, chloride and calcium (Konuspayeva *et al,* 2022; Vincenzetti *et al,* 2022).

Table 2. Average chemical composition (g/l) of camel, goat and sheep milk in the Tunisian arid land.

Composition (g/l)	Source of milk		
	Camel	Goat	Sheep
Dry matter	107,17 ±1,58[c]	143,46 ±2,17[b]	151,17 ±2,60[a]
Ash	8,92 ±0,49[a]	8,76 ±0,48[b]	7,57 ±0,97[c]
Fat	33,6 ±0,11[c]	41,3 ±0,75[b]	52 ±0,55[a]
Protein	38,6 ±0.07[a]	24,9 ±0.17[c]	35,85 ±4.21[b]

The data is given as the mean±SD.
Values with different alphabetic signify a statistically significant variation between the means (p<0.05).

Additionally, the difference in protein content could be attributed to the genetic variation among these animal species. (Yasmin *et al,* 2020). Also, factors such as the differences in breed and geographical region, type of pasture and herd management could also influence the protein content of milk (Faye *et al,* 2010; Bouhaddaoui *et al,* 2019; Seifu, 2022).

Likewise, the protein content could affect the nutritional value and the technological suitability of milk (Seifu, 2022). The camel milk is therefore, more beneficial for human nutrition because of its higher protein content and essential amino acids compared to goat milk and sheep milk. Furthermore, the protein in camel milk is easier to digest, making it a suitable option for those with lactose intolerance or digestive issues (Swelum *et al,* 2021).

The concentration of dry matter in milk samples collected from the 3 speices reavealed that the dry matter in sheep milk (151.17 g/l) was higher than that in camel (107.17 g/l) and goat milk (143.46 g/l) at highly significant (p<0.001) level. The dry matter is low in camel milk as compared with the other milks goat and sheep. These results are similar to those findings reported by Yasmin *et al* (2020) and Khaldi *et al* (2022). Many other studies have shown that sheep milk has the greatest average dry matter value among all ruminant milks, especially camel milk (Bornaz *et al,* 2009; Asif, 2010; Elbagerma *et al,* 2014; El-Hatmi, 2015; Vincenzetti *et al,* 2022). Indeed, a number of factors, including breed, nutrition, lactation stage and individual genetics could affect the dry matter content of milk (Seifu, 2022). Similarly, it was shown that the amount of water consumed by camels and the amount of solids in their milk were inversely correlated (Alaoui *et al,* 2019; Seifu, 2022).

The amount of fat content in sheep milk (52g/l) was higher ($p<0.001$) than that in the milk of other species. In previous studies, the fat content in sheep milk (Dhaoui *et al,* 2019) and in goat milk (Arroum *et al,* 2016; Ayeb *et al,* 2016; Fguiri *et al,* 2017) was found to be higher compared to finding (41.3 g/l) in the present study. However, our findings was higher to those reported by Sboui *et al* (2016) for goat milk and similair to that obtained by Khaldi *et al* (2021) for sheep milk. These variations in literature could be attributed to various factors such as breed variations, feeding practices, environmental factors, milk processing and lactation stage (Dhaoui *et al,* 2019; Chamekh *et al,* 2020; Mollica *et al,* 2021) .

Likewise, camel milk had the lower fat (33.6g/l) content than ovine and caprine milk samples. This value was in the range of the fat content values registered previously for Tunisian camel milk (Sboui *et al,* 2009; Khaldi *et al,* 2021; Hamouda *et al,* 2022). According to the literature (Bulca and Sarikoç, 2016; Seifu, 2023; Kumar *et al,* 2016), the fat in camel milk is characterised by a higher proportion of unsaturated fatty acids than milk from other species. The high content of long-chain unsaturated fatty acids (C14-C18) in camel milk could be advantageous for reducing risk factors associated with cardiovascular diseases (Karaman *et al,* 2022; Chamekh *et al,* 2023). Additionally, camel milk has a lower carotene content compared to other types of milk. Due to its low carotene concentration, camel milk is noticeably white (Swelum *et al,* 2021; Seifu, 2023).

3.2. Microbiological features

The overall microbiological quality of camel, sheep and goat raw milk were presented in table 3. Our data shows that significant differences were observed in the microbial load among the different types of milk. Except for total aerobic mesophilic flora, which surpasses the French regulatory limit on the hygiene of milk and dairy products (> $5x\ 10^5$ CFU/ml), all of the examined samples met AFNOR (2001) criteria.

In this regard, based on the high contents of lactic acid bacteria (LAB) and the lowest count of total mesophilic aerobic bacteria (TMAB), yeasts (Y), molds (M) and total coliforms (TCC), camel milk had a better microbiological quality than goat milk and sheep milk.

The presence of high concentration of total germs in raw milk could be an indice of the poor hygienic quality and inadequate sanitation practices during milking (Atigui *et al,* 2023). Meanwhile, the presence of lactic acid bacteria (LAB) in milk contributes to the improvement of its quality (Arroum *et al,* 2023) by converting lactose into lactic acid, which act as preservatives and enhances flavour (Seifu, 2022).

The average TMAB, TCC, LAB, Y/M counts of camel, goat and sheep milk observed in the present study was lower than the values reported by Fguiri *et al* (2017). Concerning sheep milk, our findings were closer to those advanced in the literature by (Khaldi *et al,* 2022). For camel milk, it's also reported that our results are lower than cited by Alaoui *et al* (2019) and higher than the values found by Karaman *et al* (2022). Therefore, based on this study and previous research, the bacterial count in camel milk was found lower compared to the sheep and goat milk.

According to many authors (El-Hatmi, 2015; Fguiri *et al,* 2017; Alaoui *et al,* 2019; Swelum *et al,* 2021; Karaman *et al,* 2022), these results could be explained by the presence of certain components in raw camel milk, such as a high lysozyme concentration and vitamin C cotent that inhibit the growth of germs. Additionaly, its could be due to its soluble proteins (lactoferrin, lactoperoxidase and immunoglobulins) having antimicrobial properties .

Indeed, the high content of these compounds in camel milk, contributing to its lower bacterial load

Table 3. Average of various flora (cfu mL^{-1}) enumerated in raw camel, goat and sheep milk in the Tunisian arid land.

Source of milk \ Flora cfu ml^{-1}	LAB	TCC	TMAB	YM
Camel milk	$8,8\pm 0.20\ 10^3$ c	$0, 2 \pm 0.12\ 10^2$ b	$6, 5 \pm 0.6\ 10^8$ b	$2, 18\pm 0.20\ 10^2$ c
Sheep milk	$4,20 \pm 0.26\ 10^4$ a	$1,5 \pm 0.1510^2$ a	$6,9 \pm 0.4\ 10^8$ b	$4,3\ 8\pm 0.6\ 10^2$ b
Goat milk	$3,5\ 8\pm 0.31\ 10^4$ b	$1,6 \pm 0.34\ 10^2$ a	$3 \pm 0.2\ 10^9$ a	$5,9\ 8\pm 0.\ 310^2$ a

The data is given as the mean±SD.
Value with different superscript signify a statistically significant variation between the means ($p<0.05$).

compared to other milk, suggests that it could be a valuable resource for developing antimicrobial agents and fermented products. However, the relatively high total mesophilic aerobic bacteria (TMAB) in camel milk, reaching 6, 5 ± 0.6 108 UFC/ml, highlights the importance of strict hygiene measures throughout the camel milk value chain.

In this study, the investigation of physico-chemical composition and bacteriological properties of camel milk from Tunisian arid lands compared to that of local goat and sheep milk, revealed significant differences in the milk characteristics among the studied species.

The analysis of the camel milk revealed the highest concentrations of protein and ash content, while, the sheep milk showed the highest concentrations of fat and dry matter. These differences in composition between camel, sheep and goat milk have important implications for their nutritional value and technological properties. The high protein and ash content of camel milk make it a valuable raw material for the dairy industry and a nutritious food for human consumption.

On the other side, the microbial content revealed a best microbiological quality for camel milk compared to goat and sheep milk. However, the total counts of FMAT for camel milk and other types of milk were below the acceptable limits and did not conform to official standards. This indicates the necessity of applying good sanitary practices and implementing proper hygiene throughout the entire milk production process.

This comparative milk study could help in understanding the composition, nutritional profile, safety and quality of camel, goat and sheep milk. This provides a solid foundation to guide consumer choices and develop new dairy products.

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