Baseline composition and microbial quality assessment of raw milk from endemic small ruminants and *Maghrebi* camels in the oasis area of Tunisia

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Abstract

Characteristics and quality aspects of milk from native ovine queue fine de l'Ouest (QFO) and the local goat population were investigated and compared with those of the local *Maghrebi* camel. A total of 378 individual milk samples were collected from lactating animals reared in the continental oasis region of Tunisia. Samples were analyzed for physical parameters (pH, density, and acidity), chemical composition (dry matter, fat, protein, lactose, casein, ash, and casein-protein ratio), mineral concentrations (Ca, P, Na, and K) and microbiological features (total mesophilic aerobic bacteria (TMAB), total coliform count (TCC), lactic acid bacteria (LAB), sulphite-reducing Clostridium (CSR), yeast and molds (Y/M), *Staphylococcus aureus* (*S. aureus*), *Escherichia coli (E. coli*), and *Salmonella*) according to standard methods. The results obtained for milk characteristics revealed noticeable disparities between the three species. The mean values of pH, density, and acidity in milk collected from sheep appeared higher than those in milk collected from goat species. Compared to the camel populations, sheep species produced milk with similar pH but higher density and acidity. Between camel and goat species, pH and acidity were higher in *Negga*, while the density was similar. For milk composition, the results showed a remarkable variation among all studied species and an obvious superiority of the ovine species over the caprine and camel populations in all the chemical contents being studied, except for the casein-protein ratio, which is in favor of goat species. The milk of QFO sheep, the richest in casein and protein, was expressed with significantly higher levels of calcium and phosphorus than goat and camel milk. Compared to small ruminants, milk from camels is the richest in Na and K. Additionally, more Ca is present in milk from camels than goats. Goat milk, the poorest type of milk in Ca and Na, contains on average more P than camel milk and more K than sheep's milk. The poor bacteriological quality was that of camel milk for all microbial counts. The microbial quality of goat milk was higher than that of ewe milk based on TMAB, TCC, and *E. coli* counts, while ovine milk was of better quality, referring to LAB, Y/M, and *S. aureus* values. No significant differences were found for *Staphylococcus aureus* and *Escherichia coli* between the examined species. The obtained results highlighted the complete absence of the two dangerous pathogens *Salmonella* and CSR in all investigated milk samples. The microbiological examination evidenced that the milk of small ruminant species complies with standard criteria required by Tunisian legislation on the hygiene of milk and dairy products. Regarding camel milk, the microbial analysis revealed poor quality that exceeds standard criteria.

1. Introduction

Dominating global and national milk production, bovine milk is by far the most commonly consumed type in Tunisia. However, in certain parts of the country and local contexts, milk from other animal species also has a significant share in milk consumption. In recent years, opportunities for non-cattle milk production and manufacturing products have expanded because the numbers of dairy cattle are perceived to reach their limit from environmental perspectives (Roy et al. 2020) and owing to quantity (15% of global milk production) and economic, cultural, and ecological factors (Rafik et al. 2016). Non-cattle milk is also believed to have certain nutritional benefits compared with cattle milk. For example, goat, sheep, camel, horse, and donkey milk are considered relatively more easily digestible, less allergenic, and more similar to human milk than cattle milk. In addition, non-cattle milk can be utilized for developing high-value specialized dairy products of international and regional (local cultural) importance, such as cheese, yogurt, butter, ghee, ice cream, fermented milk, probiotic dairy drinks, milk tablets, and infant formulas (Roy et al. 2020).

Genetic resources encountered in the Tunisian oasis area show the dominance of sheep, goat, and camel species, mainly local breeds counting 679204, 315150, and 50000 heads, respectively (DGEDA, 2018). The dominant sheep breed is the Queue Fine de l'Ouest (QFO), known as "Bergui" or "Gharbi", which is dual-purpose (for milk and meat production), well adapted to dry areas, and reared in an extensive pastoral system (Khaldi et al. 2020). The most widespread goat is essentially the local population characterized by its great diversity and heterogeneity (Nafti et al. 2014), high resistance to pathogens, and good adaptation to rather hard conditions (Ayeb et al. 2016). Indigenous goats are raised within an extensive pastoral system and semi-intensive oasis system where animals are used for meat production and substantial milking intended for local consumption (Vacca et al. 2009) or transformation for local products occurs (Leben, D'hen, Rayeb…) (Gaddour et al. 2014). The camel species, which is the most suitable animal anatomically and physiologically adapted to a harsh and painful drought environment, is entirely composed of the *Maghrebi* population. Animals are raised mainly within two management systems in the country's south, a traditional pastoral system and a semi-intensive system created in response to the decline of pasture (Fguiri et al. 2018). Camels are traditionally used for meat production (Chamekh et al. 2020), and substantial milking is intended for local consumption (Ayadi et al. 2009). Over recent decades, in oasis regions, a camel milk sector for marketing and human consumption has emerged throughout Tunisia.

It is well documented that the milk of all mammals contains the same principal components, but their content varies widely between species (Roy et al. 2020). Even within the same species, the milk composition may vary considerably, given the influence of genetic factors (not only at the species level but also at the breed level), physiological factors (e.g., lactation stage, milking interval, parity), nutritional factors (e.g., feed energy value and composition), and environmental conditions (e.g., location, season) (Claeys et al. 2014).

Except for the dairy Sicilo-Sarde sheep breed, little information is available on the characteristics of milk from mammalian species in Tunisia. Such studies on physicochemical composition and bacteriological quality are extremely limited for sheep, goats, and one-humped camels raised in western oasis areas. The limited literature available refers only to the local goat (Gaddour et al. 2014; Ayeb et al. 2016) and camel species (Ayadi et al. 2018; Fguiri et al. 2018; Chamekh et al. 2020) reared in the southeastern region. Indeed, there is no study report on the content of casein, the concentrations of minerals, the number of bacteria, and the prevalence of pathogenic germs in small ruminant milk. The QFO sheep breed, the most common in the southern regions, has never been the subject of scientific research on the composition and microbiological quality of milk. Information on the composition and microbial characteristics of milk is essential for improving the management of females and newborns, the successful valuation and development of dairy industries (Mestawet et al. 2012; Kondyli et al. 2012) and the marketing of products (Park et al. 2007). Investigation of milk characteristics is necessary to provide information essential to the development of efficient management plans for sustainable use and the improvement of these underexploited local genetic resources. Thus, this study aimed to assess and compare the physical characteristics, chemical composition, mineral concentrations, and microbiological quality of ewe, goat, and *Negga* milk in Tunisian oasis areas.

2. Materials And Methods

2.1 Animals and samples collection

Species of goats, sheep, and one-humped camel from private herds reared in the continental oases region of southwest Tunisia were used in this study, which was conducted in 2018 and 2019. These included milk samples from the QFO sheep breed (N= 100), local goat population (N= 229), and *Maghreb*i breed (N= 49) for camel species. Before sample collection, basic data on the animals (health status, age, calving season, lactation stage, parity number, etc.) were collected from the breeders. Small ruminant animals were selected for this study according to uniform body condition, suitable health status, equable age (4 years), parity (multiparous), lactation number (3rd lactation), and at the mid-lactation stage. Healthy camels with an average age of 9.5 ± 3.6 years, variable parities, and at the mid-lactation stage (the second and third months of lactation) were used in this study.

The QFO sheep and local goats were raised under a traditional feeding system where herds grazed on natural pasture in the oases' vicinity during the daytime (6–7 h/day) and were housed the rest of the day and overnight. Once back from grazing, animals were given 300-400 $gd^{-}1$ supplementation based on barley (DM: 91%; CP: 12.7%; NDF: 26.3%; Ash: 3.9%; Net energy content: 1817.01 kcal. $kg^{-}1$ DM), wheat bran (DM: 86.92%; CP: 14.9%; NDF: 37.7%; Ash: 4.1%; Net energy content: 1624.97 Kcal. kg^{-1} DM) throughout the year and dates (DM: 88.56%; CP: 3.11%; NDF: 17.81%; Ash: 2.69%; Net energy content: 1931.42 Kcal. kg^{-1} DM) during the period from October to June when wasted dates are available. During confinement in the evening, animals received alfalfa (*Medicago sativa)* (DM: 28.66%; CP: 19.22%; NDF: 45.3%; Ash: 14.20%; Net energy content: 1320 Kcal. kg^{-1} DM). For both species, females were kept together with their lambs/kids while in confinement during the day and in the evening, except on days when milk samples were taken.

The selected camels were maintained under traditional system management where herds grazed on natural desert pastures were mainly characterized by halophilic species around chotts and nonhalophilic plants such as *Haloxylon salicornicum, Anabasis articulata, Atriplex mollis, Atriplex halimus, Retama Raetam, Haloxylan schmittianum, Panicum turgidum, Traganum nudatum, Calligonum comosum, Calligonum azel, Aristida Pungens, Limoniastrum guyonianum, Stipagrostis pungen, Zygophyllum album, Sueda fructosa, Tamarix aphylla, Tamarix articulata, Tamarix gallica*, *Rhus tripartitum, Ephedra alata,* and other endemic plants. In times of scarcity, animals were given supplementation based on barley, wheat bran throughout the year, and dates during the period from October to June when wasted dates were available. All feedstuffs were distributed to all animals without respect to their physiological stage.

A total of 378 random samples of fresh milk were collected in the morning by direct milking from complete milking. A duplicate individual sample of 300 ml from healthy animals was collected in two sterile tubes and kept in an ice container during sampling and transportation to the laboratory. The first tube was brought to the animal production laboratory (CRRAO) for physicochemical and mineral analysis. The second tube was transported directly to the regional public health laboratory of Tozeur for microbiological analysis.

2.2 Physical and chemical analyses

Physical parameters (pH, density, and dornic acid) were determined during the same sampling day. The pH was measured at 20°C using a Consort C933 pH meter. To determine raw milk density, a Gerber thermolacto-densimeter was used, and measurements were made at 20°C. Dornic acidity was determined using the titrimetric method outlined in AOAC (2000). The milk samples were analyzed using official AOAC International analytical methods for lactose (AOAC, 2005) and ash (AOAC, 2012). Following the IDF Standard Methods, fat (IDF, 2009), dry matter (IDF, 2010), and total protein (IDF, 2014) were determined. The casein content was determined by the difference between the total nitrogen and the non-casein nitrogen determined by the Kjeldahl method (IDF, 2004). The casein/total nitrogenous matter ratio was determined to assess the cheese value of the studied milk.

2.3 Mineral analysis

Milk samples were analyzed for macrominerals, including calcium, sodium, potassium, and phosphorus. Calcium was measured according to IDF (2007) using an atomic absorption spectrophotometer (Analytikjena: nova 400). The determination of sodium and potassium was performed by Jenway flame emission spectroscopy in accordance with AOAC (1984). The colorimetric method involving the PhosphoVanado Molybdate complex (GB, 2010) was applied to quantify the phosphorus present in the milk sample.

2.4 Microbiological analyses

Samples were submitted for the microbial count of total mesophilic aerobic bacteria (TMAB), total coliform count (TCC), lactic acid bacteria (LAB), sulphite-reducing Clostridium (CSR), yeast and molds (Y/M), *Staphylococcus aureus* (S. aureus), *Escherichia coli* (*E. coli*), and *Salmonella*.

After properly mixing the raw milk samples, 1 ml was taken, and dilutions with 9 ml of peptone water were prepared for microbiological analyses. From this dilution, further decimal dilutions were prepared (ISO, 2001a) and plated on suitable media. According to the International Organization for Standardization standards (ISO), TMAB (ISO, 2013), TCC (ISO, 2006), LAB (ISO, 1998), CSR (ISO, 2003a), Y/M (ISO, 2004), *S. aureus* (ISO, 2003b), *E. coli* (ISO, 2001b) and *Salmonella* (ISO, 2009) were performed in duplicate samples, with the results being averaged, and the number of microorganisms is provided as a colony-forming unit per ml (CFU/ml). The bacterial counts were $\log_{10}$-transformed to normalize the distributions before performing statistical analysis.

2.5 Statistical analysis

Statistical analysis was performed by comparing the averages of different parameters between species being studied. The significant differences between means were determined by one-way analysis of variance (ANOVA) using the general linear model (GLM) procedure of SAS software (2004). The difference between the three species was determined by comparing the least-square means with adjusting the P values for multiple comparisons using the Tukey–Kramer test.

3. Results

The physical characteristics of the milk samples summarized in Table (1) revealed a significant difference between the three species (P<0.001). Compared with goat's and camel's milk, sheep's milk had a higher density and dornic acidity (P<0.001). The results showed that the highest pH was obtained equally (P > 0.05) for ovine and camel species, followed by goat species, which presented the lowest pH (P<0.001). The highest dornic acidity was observed in milk from sheep, followed by camel and then goat species (P < 0.001). The ovine QFO breed produced the densest milk (P < 0.001), and the least dense milk was that of the goats and *Maghrebi* camel, which did not differ significantly (P > 0.05).

Table 1. Physical characteristics (mean ± standard deviation) of sheep, goats, and camel's milk in the Tunisian oasis region.

Species	Traits		
	pH	Density	Acidity (°D)
Sheep	6.61 ± 0.08^{a}	1032.98 ± 3.11^{a}	20.61 ± 3.23^{a}
Goat	6.54 ± 0.09^{b}	1031.05 ± 2.82^{b}	15.96 ± 2.09^{c}
Camel	6.63 ± 0.22^{a}	1030.63 ± 2.54^{b}	19.11 ± 4.08^{b}

[a, b, c] values with different superscripts within the same column are significantly (p< 0.001) different.

The chemical composition of milk differed significantly (P < 0.001) between the species under study (Table 2). Sheep's milk had the highest (P < 0.001) dry matter, fat, protein, lactose, casein, and ash contents. The local goat population occupies the second ranking for all study components. Finally, the camel population recorded the lowest values for chemical constituents under study.

Although ovine species were superior in terms of casein and nitrogen content, the casein-protein ratio was higher among caprine species (0.80), followed by sheep breed (0.77) and last camel population (0.74) (P < 0.001).

Table 2. Average chemical composition (mean ± standard deviation) of sheep, goat, and camel's milk in the Tunisian oasis area

Species	Traits (g/L)						
	Dry matter	Fat	Protein	Lactose	Casein	Ash	Casein/Protein
Sheep	204.13 ± 29.87^{a}	59.59 ± 3.98^{a}	55.33 ± 4.17^{a}	44.25 ± 6.47^{a}	42.67 ± 3.22^{a}	10.76 ± 1.43^{a}	0.77 ± 0.26^{b}
Goat	132.94±23.98b	40.45 ± 6.24^{b}	35.43 ± 6.05^{b}	40.48 ± 5.44^{b}	28.58 ± 4.76^{b}	7.93 ± 1.64^{b}	0.80 ± 0.1^{a}
Camel	115.24±15.67^{c}	32.84 ± 4.88^{c}	30.97 ± 6.40^{c}	37.21± 4.64^{c}	22.77 ± 4.27^{c}	6.87 ± 1.59^{c}	0.74 ± 0.07^{c}

$^{a, b, c, d}$ *values with different superscripts within the same column are significantly (p< 0.001) different.*

As depicted in Table 3, species exhibited significant differences (P < 0.001) in calcium, phosphorus, sodium, and potassium concentrations. Regarding mineral concentrations, the results showed that milk produced by ewes had the highest contents of calcium and phosphorus (P < 0.001). Compared to the goat species in terms of calcium and phosphorus, camel milk was richer in calcium (P < 0.001), while goat's milk contained more phosphorus (P < 0.001). In contrast, for the other major minerals, Negga milk was found to be richer in sodium and potassium (P < 0.001) than small ruminants. Ewes produced milk with more sodium concentration and less potassium than goats (P < 0.001).

Table 3. Mineral contents (mean ± standard deviation) of sheep, goat, and camel’s milk in the Tunisian oasis area.

Species	*Minerals* (g/L)			
	Ca	P	Na	K
Sheep	2.02 ± 0.27^{a}	1.45 ± 0.19^{a}	0.40 ± 0.05^{b}	1.30 ± 0.17^{c}
Goat	1.40 ± 0.29^{c}	1.18 ± 0.24^{b}	0.28 ± 0.08^{c}	1.49 ± 0.30^{b}
Camel	1.60 ± 0.17^{b}	0.58 ± 0.18^{c}	0.50 ± 0.13^{a}	1.81 ± 0.33^{a}

$^{a, b, c, d}$ *values with different superscripts within the same column are significantly (p < 0.001) different.*

The bacteriological quality of different types of milk is given in Table 4. According to the results, the microbial quality of goat’s milk was higher (P < 0.001) than that of sheep and camel milk based on TMAB, TCC, and *E. coli* counts. Ovine milk was of better quality, referring to LAB, Y/M, and *S. aureus* values (P < 0.001). The poor bacteriological quality was that of camel milk for all microbial counts.

The total mesophilic aerobic bacteria (TMAB) and *Escherichia coli* counts in the *Maghrebi* camel were significantly higher (P <0.001) than those in the QFO sheep and local goats. Based on the total coliform (TCC) and *S. aureus* counts, camels still recorded higher levels of contamination (P < 0.001) than those of sheep and goat species, which did not differ significantly (P > 0.05).

Lactic acid bacteria (LAB) and molds and yeasts (Y/M) values enumerated in this study for each species were higher in camel milk than in goats and QFO sheep at a highly significant level (P < 0.001).

The three species analyzed were significantly different (P < 0.001) from each other for the average molds and yeasts (Y/M) and lactic acid bacteria (LAB) values. Levels of contamination were higher in camel milk than in goat and QFO sheep. In all investigated samples, pathogens, sulphite-reducing Clostridium (CSR), and *Salmonella* were absent throughout.

Table 4. Bacterial counts (log_{10} CFU/mL) in the milk of studied species from the Tunisian oasis region.

Species	Microbial Flora							
	TMAB	TCC	LAB	CSR	Y/M	*S. aureus*	*E. coli*	*Salmonella*
Sheep	$5.44±0.31^{b}$	$3.24±0.30^{b}$	$3.03±0.31^{c}$	0	$3.19±0.06^{c}$	$0.40±0.77^{b}$	$0.43±1.01^{b}$	0
Goat	$5.17±0.31^{c}$	$3.20±0.31^{b}$	$3.44±0.32^{b}$	0	$3.66±0.21^{b}$	$0.47±0.79^{b}$	$0.25±0.83^{c}$	0
Camel	$6.54±0.35^{a}$	$5.16±1.49^{a}$	$3.77±0.65^{a}$	0	$4.22±1.06^{a}$	$1.66±1.63^{a}$	$2.64±0.85^{a}$	0

^{a,b,c,d} values with different superscripts within the same column are significantly (p< 0.001) different.

TMAB: Total mesophilic aerobic bacteria; TCC: Total coliform count; LAB: Lactic acid bacteria; CSR: Sulfite-reducing Clostridium; Y/M: Yeast and molds; S. aureus: Staphylococcus aureus; E. coli: Escherichia coli.

4. Discussion

4.1 Basic composition of ewes, goats, and Negga's milk

In terms of milk composition, our results revealed a significant variation between all species. The results showed that sheep species were clearly superior to the population of goats and camels in all chemical contents being studied, with the exception of the casein-protein ratio, which favors goat species. The distinctions are more significant, particularly in terms of dry matter, fat, protein, casein, and ash content. Many more studies have confirmed that sheep milk has the greatest average value of the above constituents than goats (Park et al. 2007; Kondily et al. 2012.) and camel's milk (Claeys et al. 2014; Ysamin et al. 2020). Likewise, the ancestry of goats relative to camel species in the above chemical constituents has been reported by several authors (Legesse et al. 2017; Yasmin et al. 2020). Nevertheless, many factors might significantly affect the major and minor composition of milk, such as individuals, parity, season, diet, management, environmental conditions, locality, lactation stage, and udder health status (Park et al. 2007), yet the special difference because of genetics always has pronounced contributions (Yasmin et al. 2020).

According to the literature, the milk composition of sheep, goats, and camels varies from medium to large-scale (Park et al. 2007; Rouissi et al. 2008; Chamekh et al.2020; Hilali et al. 2011; Kondily et al. 2012; Claeys et al. 2014; Monteiro et al. 2019). Several studies were conducted in Tunisia to study the chemical composition of milk from native and exotic breeds of sheep, goats, and camels. Milk from local QFO gave in this study total solids, fat, protein, casein, and ash content comparable to those reported by El Gharbi et al. (2015) for Barbarin sheep breed reared in a semiarid climate but was lower than findings of Aloulou et al. (2018) for Sicilo-Sarde ewes and those of Rouissi et al. (2008) for Sicilo-Sarde and Comisane dairy sheep breeds raised in an intensive system in the extreme north of the country. The variation from the reported results could be attributed mainly to the difference in the breed, management conditions, including feeding, and environmental factors, among others. Compared to the results from the exotic D'man breed maintained under an intensive oasis system in southeastern Tunisia (Dhaoui et al. 2019), our findings are higher for all chemical compounds, except for the fat content, which was lower.

Concerning lactose content, QFO milk showed higher levels than those reported for Sicilo-Sarde (Rouissi et al. 2008; Aloulou et al. 2018), Barbarin (El Gharbi et al. 2015), and Comisane (Rouissi et al. 2008). Similar lactose content in the D'man breed was found by Dhaoui et al. (2019) in Tunisia.

The relatively high concentrations of dry matter, fat, and protein, as well as other nutritious components, can assure the growth of a newborn kidlet. This result implies that abundant milk fat and total solids are relevant characteristics of

Tunisian sheep milk. It is commonly accepted that milk from breeds with low potential milking yield from the Mediterranean and tropical areas is more concentrated in total solid, fat, and protein than the highly productive breeds from temperate regions (Hernández-Castellano et al. 2019).

The results of goat milk comply with those of Tunisian native goats (Ayeb et al. 2016), native Greek breeds (Capra Prisca) (Kondily et al. 2012), and Algerian Arabia (Hamidi et al. 2020). Higher content levels were noted in the Boer and Arsi-Bale Ethiopian goat breeds (Mestawet et al. 2012) and Murciana-Granadina, Boer, and La Mancha goat breeds (Ferro et al. 2017). The variation in the results from different literature sources could be related to the genetic potential of breeds, management conditions, environmental factors, feeding, and lactation stage at which samples were taken (Currò et al. 2019).

Milk from she-camel gave in this study total solid, fat, protein, casein, lactose, and ash comparable to that reported by Jemmali et al. (2016), Hamed et al. (2012) but was lower than findings by Ayadi et al. (2009) and higher than that founded by Chamekh et al. (2020) except for ash which is higher than in our study. The variation from the reported results could be attributed mainly to the difference in management conditions, including feeding and environmental factors. Out of Tunisia, current results approached those of the Egyptian *Maghrebi* camel (Abdalla et al. 2015) and native Turkish breed (Karaman et al. 2021). Lower content levels were noted in Ethiopian and Saudi camels (Al Haj and Al Kanhal 2010). The variation in the results from different literature sources could be related to the region, the genetic potential of breeds, management conditions, environmental factors, feeding, and lactation stage at which samples were taken (Chamekh et al.2020).

The casein-protein ratio with the largest value was found in goat milk (0.80), followed by sheep (0.77), and the smallest was found in camel milk (0.74). Similarly, the results for the casein-protein ratio are in line with other investigations in goats (Vacca et al. 2018) and sheep breeds (Rafik et al. 2016). Our finding is higher than that attained with the same *Maghrebi* dromedary population from the south and the center of Tunisia (Attia et al. 2000; Hamed et al. 2012) and similar to that in other breeds (Farah, 1993). The results inferred that the lowest concentration in whey protein was that of goat milk, and the highest concentration was that of camel milk (Hilali et al. 2011). The increase in whey protein has technological implications, such as a weaker texture of curd and lower cheese yield (Barlowska et al. 2020). Proteins are a determinant factor affecting the quality of dairy products, as the reduction in proteins and casein contents results in poor dairy technology-making properties (Hilali et al. 2011). In another way, a lower casein-to-whey-protein ratio (i.e., a higher proportion of whey proteins) has been shown to be more desirable for faster digestion of the milk proteins in infant formula than a casein-dominant protein composition (Roy et al. 2020), which is the case of camel milk, recently declared very similar to human milk in terms of qualitative whey protein profile (El-Hatmi et al. 2015) and as a most suitable substitute for cow milk when considering the preparation of infant formulas (Mudgil et al. 2022).

4.2 Physical characteristics

On the whole samples, the mean value of all physical characteristics (pH, density, and Dornic acidity) in milk collected from sheep breeds appeared higher than in milk collected from goat species. Compared to the camel populations, sheep species produced milk with a similar pH but a higher density and acidity content. Between camel and goat species, pH and acidity were higher in *Negga*, whereas the density was identical in both species.

Many earlier findings on the physical parameters of sheep, goats, and camel milk corroborate the results of the current investigation (Park et al. 2007; Ayeb et al. 2016; Al Haj and Al Kanhal, 2010) and differ from other works (Hilali et al. 2011; Kondily et al. 2012; Ismaili et al. 2019). The pH and acidity levels are indicators of the health status of animals and hygienic quality milk. However, milk from healthy animals should have pH values from 6.5 to 6.8 in small ruminants (Park et al. 2007) and from 6.4 to 6.7 in camels (Singh et al. 2017). A lower pH of fresh milk may be because of bacterial actions, and higher pH values indicate udder infection or mastitis (Carloni et al. 2016). The pH of milk is the most critical factor in producing various dairy products. It determines the conformation of proteins, the activity of enzymes, and the dissociation of acids present in milk (Rafik et al. 2016). High acidity indicates high numbers of microorganisms and consequent development of lactic flora, influenced by the combined effect of temperature and storage conditions (Ismaili et al. 2019). Along with pH, titratable acidity provides information about the total solids content of the milk and freshness, making it an important feature when defining quality.

The physical properties of milk are widely reported to be associated with its composition and animal species (Park et al., 2007; Hilali et al. 2011). The fat content associated with total solids in milk has a determining influence on its density, as has already been explained by other authors. (Park et al. 2007).

4.3 Mineral concentration

The variations in mineral concentrations among animal species are indicated in Table 3. The current results revealed considerable differences in the mineral concentrations of milk from different species. The levels of Ca and P are higher in sheep than in goat and camel milk. Compared to small ruminants, milk from the camel is the richest in Na and K. Additionally, more Ca is present in milk from camels than goats. Goat milk, the poorest type of milk in Ca and Na, contains on average more P than camel milk and more K than sheep's milk.

When comparing sheep breed versus goat milk for macroelements, the current study found lower levels of K and higher concentrations of Ca, P, and Na. Other research studies reported higher concentrations of K in sheep milk (AL-Wabel, 2008). The ascendance of sheep in Ca, P and Na and lower K levels compared to goat species was mentioned by Hilali et al. (2011). In the same way, Monteiro et al. (2019) declared that sheep milk is the type of milk that has the highest amount of calcium and phosphorus, while a high potassium content distinguished goat milk. Our results lie within the ranges reported in the literature for sheep (Hilali et al. 2011) and goat breeds (Monteiro et al. 2019).

The phosphorus content in camel milk from Tunisian oasis areas appeared at similar levels to those of the literature (Konuspayeva et al. 2010; Singh et al. 2017) and at lower concentrations than others (Faye et al. 2008). The results from the current study revealed that a high concentration of potassium was detected. These results align with those of several authors (Singh et al. 2017).

Camel milk is a rich source of minerals, especially Ca and K (Benmeziane-Derradji, 2021), because of the forage eaten by camels such as Atriplex and Acacia, which usually have a high salt content and are possibly the reason for the salty taste of milk (Singh et al. 2017). According to Benmeziane-Derradji (2021), camel species have greatly higher concentrations of Na and K than small ruminants, which agrees with the results of our study. Nevertheless, variations in mineral content are closely dependent upon animal species (Clayes et al. 2014), breed differences (Al Haj and Al Kanhal 2010), individual animals, stage of lactation, udder health status (Stocco et al. 2019), production system (Singh et al. 2017), analytical procedures (Attia et al. 2000), water intake (Singh et al. 2017), and nutritional status and diet (Pietrzak-Fiećko and Kamelska-Sadowska 2020).

Low Na concentrations were obtained for all species, which is similar to previous works in camel (Benmeziane-Derradji, 2021), goats (Currò et al. 2019), and sheep breeds (Khan et al. 2006) but in contrast with other studies, which reported higher levels in camel (Singh et al. 2017), goats (Stergiadis et al. 2019), and sheep species (Monteiro et al. 2019). This variation could be attributed to the lactation stage; in fact, the Na concentration in sheep and goat milk is higher at early lactation than during middle and late lactation (Khan et al. 2006).

4.4 Microbiological features

The microbial quality of goat milk was higher than that of ewes and *Negga's* milk based on TMAB, TCC, and *E. coli* counts. Ovine milk is of better quality, referring to LAB, Y/M, and *S. aureus* values. The poor bacteriological quality was that of camel milk for all microbial counts.

S. aureus and *E. coli* were prevalent in all milk types with different levels of contamination. Two primary sources cause *Staphylococcus* in milk: the first is the lack of adequate hygiene measures and inappropriate handling during milking (Fatima et al. 2013), whereas the second is mastitis, which affects animals (Benmeziane-Derradji, 2021). In the current study, the selected animals were healthy and milked respecting hygienic practices; thus, *Staphylococcus* prevalence in the milk samples may be linked to subclinical mastitis occurrence (Alebie et al. 2021).

No significant differences in the numbers of total coliform populations (TCCs) were noted between the milk of the studied species, except *Maghrebi* animals, which generate milk with the highest count. Higher TMAB, TCC, LAB, Y/M, *S. aureus*, and *E. coli* counts in ewe milk were obtained by Fatima et al. (2013). In goat milk, Tabet et al. (2016) detected higher counts, and Kalhotka et al. (2015) reported higher bacterial results in both species. Lower total bacterial counts have been observed in goats (Abd El Aal and Awad 2008) and sheep's milk (Tonamo et al. 2020).

As stated in the results, camel milk exhibited a high rate of FAMT. These results are nearly similar to those reported by Adugna et al. (2013) and Wasie et al. (2015) and higher than those cited by Karaman et al. (2021) and Abera et al. (2016). Extremely high burdens of FMAT exceeding 8 $\log_{10}$ CFU/mL were found by Ismaili et al. (2019). Concerning total coliform counts, our findings were closer to those advanced in the literature by Wasie et al. (2015) and lower than the values of Benkerroun et al. (2003), Benyagoub and Ayat (2015), and Ismaili et al. (2019).

The average count of LAB was 3.77 ± 0.65 $\log_{10}$ CFU/mL at a low level. The count number was lower than those reported by Benkerroum et al. (2003) and Ismaili et al. (2019). The high levels of lysozyme and ascorbic acid in camel milk may explain the low level of LAB, as mentioned previously by other researchers (Karaman et al. 2021). The yeast and mold count of the camel's milk samples in this study was 4.22 ± 1.13 $\log_{10}$ CFU/mL. The average value is less than the values found in camel's milk samples in Sudan (Karaman et al. 2021) and Morocco (Ismaili et al., 2019). The lower yeast and mold counts could be because the natural milk pH favors bacterial growth and lowers yeast and mold content, as detected in the samples of this study (Karaman et al. 2021). In studies achieved in Tunisia on the same camel breed and focused on the enumeration of the mesophilic count, total LAB, and coliforms, lower levels were cited by Fguiri et al. (2018).

High total bacterial counts in raw milk mainly reflect the poor hygienic condition under which the milk was handled, storage temperature and time elapsed since milking, and the poor health of milking animals (Adugna et al. 2013). With the current study, the main source of contamination could be attributed to the contamination of the camel udder by the hands of unhygienic milkers or unhygienic milking procedures. Microorganisms can be transferred from the environment, i.e., feces, bedding, and soil, from contaminated hands, clothing, and mouth of milk handling personnel (Alebie et al. 2021).

The conducted study showed a complete absence of the two dangerous pathogens *Salmonella* and sulphite-reducing Clostridium in all examined samples of milk, suggesting that both pathogens are uncommon in small ruminant and camel's milk in the herds sampled. Several studies advanced a similar finding for goat milk (Tabet et al. 2016), sheep milk (Fatima et al. 2013), and camel milk (Benyagoub and Ayat 2015). Various studies have shown that several factors can affect the bacteriological quality of milk, including animal breed (Tonamo et al. 2020), milking practice, stage of lactation (Nagy et al. 2013; Fguiri et al. 2018), farm characteristics and practices (Abera et al. 2016), years and season (Kondily et al. 2012; Ismaili et al. 2019), housing conditions and feeding practices (Fguiri et al. 2018), animal health, flock size and hygiene of premises and milk tank parlors (Carloni et al. 2016).

The results from the current study showed that the levels of microbial contamination of raw small ruminant milk in the oasis regions of Tunisia were satisfactory. Microbiological analysis meets the standard criteria required by Tunisian legislation on the hygiene of milk and dairy products (NT 14.141 (2004)). In contrast, the results showed that the levels of microbial contamination of raw camel milk in the study area were unsatisfactory and could not comply with the standard requirements of Tunisian legislation. Camel milk is commonly produced, conserved, and transported under unhygienic conditions. The bacteriological quality of raw milk should therefore be a major concern for farmers, processors, and the general public because bacteria in milk can degrade milk components, decrease shelf life, and cause illnesses in human beings (Adugna et al. 2013).

5. Conclusion

The current results contribute to the characterization of local camel, goat, and sheep breeds raised in Tunisian oases regions regarding physicochemical composition, mineral content, and bacteriological properties of milk. The results revealed notable differences between the three milk types and the particular characteristics that differentiate each species. Indeed, the QFO sheep breed generates the best milk in terms of density, acidity, dry matter, fat, protein, casein, ash, Ca, P, LAB, Y/M, and S. aureus count. The Na and K concentrations distinguished the *Maghrebi* camel, where the local goat population produces milk with relevant casein-protein ratios, TMAB, TCC, and *E. coli* counts. The analysis of small ruminants and camel milk reveals good physicochemical characteristics and appreciable mineral profiles compared to standards encountered in the scientific literature. The bacteriological quality was satisfactory and complied with the standards criteria required by Tunisian legislation for small ruminant milk. For camel milk, the microbial analysis revealed poor quality that exceeds the standards, requiring strict hygienic control along the value chain.

With such interesting properties, the milk of local animal genetic resources in oasis areas is ideal for manufactured dairy products, which creates excellent opportunities for small breeders to increase their incomes, value autochthonous breeds and preserve their biodiversity.

Declarations

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Conflicts of interest/Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Code availability

Not applicable

Authors' contributions

Zahran Khaldi was responsible for the study design, milk sample collection, physicochemical and mineral analysis, contributed to the microbiological analysis, performed statistical analysis and interpretation of data, drafted the manuscript, and was a major contributor in writing the manuscript. **Zahran Khaldi** is the corresponding author.

Mounir Nafti participated in the study design, and the milk sample collection, physicochemical, and mineral analysis contributed to the microbiological analysis, analysis, and interpretation of data and was a contributor in writing the manuscript.

Mohamed Tabarek Jilani took part in the design of the study, performed the microbiological analysis of milk samples, and participated in the data interpretation.

Zahran Khaldi written the first draft of the manuscript, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

Not applicable

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