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Effect of milking routines and hygiene practices and evolution along the market value chain on raw camel milk quality in Tunisia

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ABSTRACT
This study investigated the effect of on-farm practices on milk production, chemical and microbiological quality and on Somatic Cell Count (SCC) as well as the evolution of milk quality along the camel dairy value chain in southern Tunisia. A survey of 12 periurban dairy camel farms showed that the use of machine milking is limited (16.7%). The milking hygiene practices need to be improved with only 25% of farmers practiced teat dipping and washed the material with hot water and detergents. In addition, 75% of farmers milked their animals in bedding area. Conservation and marketing conditions for raw camel milk were mediocre. Analysis of on-farm milk quality showed that use of machine milking was related to increased milk production but also caused an increase in the microbial load. Quality assessment at different stages of the production chain showed that the chemical composition of milk was conserved, whereas the physical and microbiological quality was altered. At production, the load in Mesophilic Total Aerobic Flores (MTAF) was low with 17.4×104 cfu/mL, compared to bulk and point of sale milk, which had a significantly higher load (21.2×105 cfu/mL and 61.2×105 cfu/mL, respectively). The acceptability threshold of Acidity, MTAF, Total Coliforms and *S. aureus* prevalence were exceeded in all samples purchased from points of sale. Therefore, improvements in milking hygiene, milk storage, and transport conditions are essential in order to guarantee the quality of camel's milk to meet the needs of the consumer.

HIGHLIGHTS

- The use of machine milking for dromedary camels in Southern Tunisia is limited and most she camels are milked by hand with suckling of the calf.
- Milking routine affect significantly the bacterial load of camel milk.
- Sanitation problems and keeping the cold chain are the biggest challenge in the dairy camel sector.

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Introduction

According to the Camel Milk Products Market Size Industry Report 2020–2027, global camel milk products market size was valued at 10.2 billion USD in 2019 (Smits et al., 2022) and estimated to increase rapidly across the world. Increasing demand for camel milk is due to its therapeutic and easy-to-digest among bovine milk intolerant consumers properties. The camel milk is particularly rich in numerous minor bioactive components which have special therapeutic properties compared to cow's milk (El-Agamy 2009; Konuspayeva et al. 2009; Kaskous and Pfaffl 2017; Rasheed 2017; Swelum et al. 2021). It contains higher quantities of copper, iron, sodium, zinc, potassium, magnesium, manganese, and vitamin A, B and C (Rasheed 2017) with safe limits of heavy metals for human consumption (Ahamad et al. 2017). Besides, it is one of the most nutritious dairy beverages, which includes natural probiotic in it (Fguiri et al. 2015; Edalati et al. 2019). Aside from that, camel milk helps improve systemic immunity as it contains series of protective proteins such as lysozyme, lactoferrin, lactoperoxidase, immunoglobulin G, and immunoglobulin A (El-Hatmi et al. 2006; Konuspayeva et al. 2007; Habib

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et al. 2013) and enhances gastrointestinal health (Wang et al. 2018). Additionally, the COVID-19 pandemic has proliferated the increasing recognition of camel milk added-value by consumers owing its immune-boosting effects and further increased the demand for camel milk products (Nagy et al. 2021; Al-Saffar 2022).

However, camel milk is not yet widely integrated into national market (except for some countries such Emirates and Saudi Arabia) and offline distribution channel of camel milk accounted for more than 80% of the global camel milk revenue. Consumers prefer to purchase raw camel milk straightly at farm level or from retailers owing the short shelf life and daily requirement (Bekele et al. 2021; Faraz et al. 2021; Cheikh Ismail et al. 2022). Faye (2022) described 3 main camel milk sales channels; Direct sale to consumers along the roads of raw or fermented milk. There is no specific packaging or hygienic control, but the milk is sold immediately at a remunerative price. The second channel is through retailers without specific packaging in local markets. The third sale channel, and the least represented one, is by industrial dairies in the cities where it is pasteurised or processed (fermented milk, favoured, powdered …). Thus, the camel dairy product circuit has been largely unknown and few studies have been dedicated to assess the quality and safety of camel milk available for consumption. Nonetheless, raw camel milk may contain pathogenic microorganisms as a direct consequence of udder diseases or could be contaminated along the value chain due to poor hygienic condition during milking, milk collection, transport and storage. Among these microbes, camel milk could be contaminated by pathogenic *E. coli*, *S. aureus* (Ombarak and Elbagory 2014; Alaoui-Ismaili et al. 2019) and *Salmonella sp.* (Alaoui-Ismaili et al. 2019). All microbiological counts increased along the market chain indicating a lack of hygienic conditions in the production, transportation and sale points of the raw camel milk (Kaindi et al. 2011; Alaoui-Ismaili et al. 2019).

Thus, this study aimed to investigate the effects of milking routines, hygiene practices and storage conditions on raw milk physico-chemical and microbiological quality along the informal market chain to assess the safety of its consumption on human health.

Material and methods

Data collection

The study was conducted in southern-east Tunisia (peri-urban regions of El-Hamma and Medenine cities) to assess small-scale camel's farms management and breeders' status and the milking and hygienic practices of 12 peri-urban camel herders. The survey is based on simplified, closed or open questions in order to be easy to understand by the breeders and observations during milking session.

Milk sampling

Samples were collected during morning milking session between 6.00 – 8.00 am. A total of 56 individual milk samples were directly collected from the she-camel udder in 50 ml sterile Falcon tubes after elimination of first milk squirts to determine bacterial count at udder level of camel milk. Another composite milk sample for each camel was taken after (manual/machine) milking for further analysis. Samples were also collected from the milking bucket or tank of the 12 farms and purchased from 9 sale points. Part of these samples was used instantly for pH, acidity and viscosity analysis. The other samples were kept in ice coolers and transported to the Livestock and Wildlife Laboratory of the Arid land Institute for further chemical and microbiological analysis.

During sampling, camels were carefully selected to be clinically healthy, and at early stage of lactation based on the age of the calf since not all breeders registered calving date, in order to avoid additional lactation stage effect on milk production and quality.

Physicochemical analysis

pH of camel milk samples was measured using a digital pH metre (Jenway 3510 pH metre) and their titratable acidity (°D) was obtained by titrating 10 mL of milk with N/9 NaOH, using phenolphtalein as an indicator. Milk viscosity (in cP) was measured using Brookfield type viscometer (model DV-E, MA, USA).

Total milk solids and ash were analysed by gravimetry. Fat content was determined by butyrometers using the Neusal method (Wangoh and Farah 2004). Protein content was determined by spectrophotometer using the Bradford method (Bradford 1976).

Microbiological analysis and somatic cells count

Mesophilic Total Aerobic Flores (MTAF) was carried out on Plate Count Agar (PCA, Scharlau Chemie S.A.), incubated at 37 °C for 72 h, and yeast and moulds on Sabouraud Chloramphenicol (Pronadisa) incubated at 25 °C for 3 to 5 days. Total coliforms were grown in Violet Red Bile Agar (AppliChem) in a double layer.

Lactic Acid Bacteria (LAB) were plated on De Man-Rogosa-Sharpe (MRS) agar (Scharlau Chemie S.A.) and incubated at 30 °C for 48 h.

The presumptive *Staphylococcus aureus* colonies were identified on Baird Parker medium grown on surface and incubated at 37 °C for 24 h.

Individual composite milk samples from camels were subjected to direct microscopic somatic cell count (SCC) according to standardised cell count methods. Briefly, an amount of 0.01 mL milk sample was spread over Malassez slide. The smear was stained with methylene blue stain for 10 min, followed by somatic cell count *via* direct microscopic examination.

Statistical analysis

Data are presented as means ± SE. Statistical analysis was carried out using MIXED model procedure of SAS (version 9.0, SAS Inst. Inc., Cary, NC) to evaluate the effect of breeding system and milking practice on yield, composition and hygienic status of milk. Differences between least squares means were determined with PDIFF test and significance was declared at $p < 0.05$, unless stated otherwise.

Results and discussion

Typology of small-scale dairy farms in southern Tunisia and description of milking practices and hygiene

Table 1 shows the main characteristics of the 12 visited camel farms that have dairy activities. In southern Tunisia, almost all camel herds are conducted under extensive conditions on arid and desert pasture, away from major cities except for some small scale fattening or dairy peri-urban farms as it is the case worldwide (Faraz et al. 2019; Faye 2022). During this study, we only visited farmers with some dairy activities. Most of these farms were conducted in a semi-intensive breeding system.Camels were allowed to graze during 6 to 7 hrs a day and fed with a commercial concentrate. All farmers appealed for veterinary assistance only when needed. Average herd size was 45.6 ± 28.5 head. About 62% had a herd size between 50 and 100 camels; the average number of lactating camel was 14.3 ± 8.6 while only 8.5 ± 5.3 were milked ranging from 3 to 17 milked camels/farm. Lactation period was estimated by farmers from 7 to 12 months with an average of 10.3 months.

Regarding milking routine (Table 2), most farmers milked their camels once a day (62.5%), while a group of farmers increased milking frequency to twice per day particularly when the demand for milk increased. Camels were milked by hand in most cases (87.5%). The milking procedure was always handled by men in all the studied farms and milk ejection reflex was induced by allowing the calf to suckle in 50% of cases and most milkers (75%) massaged the udder prior to milking. The milking duration lasted from 30 to 90 min per milking session depending on the number of milked camels and milking technique. The milking interval or in most cases the interval between calf separation and milking ranged between 11 to 16 hrs in the studied farms.

Table 1. Main characteristics of the studied camel farms.

Variables	Levels	%
Presence of male	Yes	87.5
	No	12.5
Management	Intensive	25
	Semi-intensive	62.5
	Extensive	12.5
Use of concentrate	Yes	75
	No	25
Veterinary control	Yes	100
Herd size		45.6 head
Size classes	<50 head	37.5%
	[50–100]	62.5%
Body condition	Average	37.5%
	Good	62.5%
Number of lactating camels		14.3
% lactating camels		36.5%
Number of milked camels		8.5
% milked camels/lactating		61.4
Lactation duration (month)		10.3

Table 2. Milking routine and hygiene in the studied camel farms.

Variables	Levels	%
Milking	Machine	12.5
	Hand	87.5
Milking frequency	Once	62.5
	Twice	37.5
Milker	One	50
	Multiple	50
Milker's gender	Male	100
Milk ejection reflex induction	Oxytocin	12.5
	Tactile	37.5
	Calf	50.0
Udder massaging	Yes	75
Pre-rinse	Warm water	50
	Cold water	12.5
	None	37.5
Udder wiping	Yes	75
Use of iodine	Yes	25
Milking equipment cleaning	Before and after milking	87.5
	After milking	12.5
	Hot water + detergent	25
	Cold water + detergent	50
	Only water	25
	Acide– alkaline cleaning	12.5
Milking equipment material	Plastic	75
	Metallic	25
Milking location	Barn	25
	Bedded area	75
Milking location status	Clean	100
	Earth	1000
	Cement	0

Regarding milking hygiene, teat pre-rinse was practiced in 62.5% of the visited farms with only 50% of them used warm water to rinse the udder. Up to 75% of milkers wiped the udder prior to milking and post-dipping procedures were less frequent (25%) mainly in machine milked camels. Milking equipment were cleaned before and after milking in 87.5% of the studied farms while the rest cleaned their milking equipment only after milking session ended.using cold water with detergent. However, deep cleaning with acid-alkaline solutions was only performed in machine milking. Milking equipments were generally quite simple in most cases, milking was performed by hand in a plastic container. Only 25% of farms reserved a particular area for milking, yet, all the visited farms took particular care for cleaning the milking area and it had a satisfactory hygienic status.

Most farmers sold camel milk straight to the consumer (62.5%) while 25% sold the excess production to retailers and sale points in the city (Table 3). A minority, produced milk for family consumption only. Up to half of the produced milk was stored in the farm to 3 days or more, while only 25% was sold immediately after milking. Most farmers stored the milk in the freezer particularly when the milk was kept for more than 3 days.

Only machine milking farms had milk tanks to keep milk cold (4–8 °C) until selling or stored it in the freezer (−18 °C) when milk production exceeded (Table 3). None of the farmers kept the milk at ambient temperature for a long time and sold it either immediately (25%) or froze it to be deliverd to a distant buyer. At this point, none of the farmers proceeded with heat treatment of camel milk. Pasteurisation or spray dried treatments of camel milk remained only experimental (Felfoul et al. 2015; Lajnaf et al. 2020; Zouari, Briard-Bion et al. 2020; Zouari, Schuck et al. 2020) despite the governmental efforts and consumer awareness. Recently, few camel milk pasteurisation units have been implemented in southern Tunisia to promote camel milk marketing and resolve the hygienic inquires of the consumers.

Table 3. Milk storage at farm level in camel dairy farms.

Variables	Level	%
Milk storage	Milk tank (4–8 °C)	25
	Refrigerator (5 °C)	12.5
	Freezer (−18 °C)	62.5
	Ambient temperature	0
Storage duration	One day	12.5
	2 days	12.5
	More	50
	Immediate selling	25
Milk utilisation	Direct selling	62.5
	Direct selling + retailers	25
	Family consumption	12.5

Effect of management and milking practice on milk production and milk quality

As shown in Table 4, all selected camels were at early stage of lactation (less than 5 month of lactation). Milk yield/milking session was significantly higher in machine milked camels under intensive management system compared to the remaining systems. Nevertheless, estimated daily milk production/camel were similar in all studied systems.

Until today, milk production is considered as a secondary activity in camel breeding. The priority is the production of meat (butcher's calf) or replacement females, thus most farmers' priority is to suckle the calve rather than produce milk. In addition, the increase in feed intake and/or the improvement in the quality of the diet is only limited to the period of high demand for milk. Otherwise, the breeder limits feed-related expenses or switches to exclusive grazing on range-lands far from urban areas. These practices are common among camel breeders in a large number of countries with low income (Faye et al. 2004). Furthermore, the quantity truly produced, which the breeder can benefit, is significantly higher in machine milked camels. Knowing that the breeder in this case benefits from all the milk produced by the animal since the stimulation of the animals depends on the pulsation of the milking liner and not on the suckling calf. For manual milking, it depends on the technique and know-how of the breeder. For instance, in the case of semi-intensive system, in order to increase the quantity of milk collected, breeders let the young calf stimulate its mother then, milk the four quarters. This practice allows them to double the quantity obtained per camel compared to others who let the calf suckles until the end of the milking session. Nevertheless, the emptying of the udder must be done rapidly since the stimulation of the camel is lifted in this case. In dairy cows, Bruckmaier et al. (1994) found that continuous stimulation of milk ejection is essential to ensure complete emptying of the udder. Exclusive hand-milking leads to a lower quality of stimulation, caused by a lower oxytocin release compared to suckling

Table 4. Effect of management and milking practice on milk yield.

	Stabling		Grazing
	Manual	Mechanical	Manual
Lactation stage (month)	4.4 ± 0.8	4.8 ± 1.4	2.5 ± 3.9
Separation time (h)	16 ± 0.0^{a}	15 ± 0.0^{b}	11.5 ± 1.2^{c}
Milk yield (L)	1.4 ± 0.6^{c}	3.3 ± 0.9^{a}	2.1 ± 0.6^{b}
Estimated Daily production (L/d)	4.2 ± 1.7	4.8 ± 1.7	4.3 ± 1.0

[a,b,c]Means in the same line with a different superscript letter are significantly different ($p < 0.05$).

(Bruckmaier and Blum 1996). Recently, it has been shown, in camels, that oxytocin discharge was similar in peak level, time of peak and total quantity released, during exclusive suckling and hand milking with simultaneous suckling. For well trained camels, the presence of milker and the touch of the udder did not alter oxytocin and cortisol release patterns induced by hand-milking (Brahmi et al. 2021). Although, it has been proved to be the best stimulation practice, the milk collection for human consumption is reduced with this management due to calf milk consumption. Hence, the recommendation of this practice is limited. Unfortunately, exclusive hand milking was not tested and the intensity of stimulation was not recorded.

This study hypothesised that milk quality would vary as a result of differences in farming systems, reflecting differences in agro-ecological conditions, the availability of production factors and the milk removal technique (Table 5). Overall, fat content was significantly ($p < 0.01$) higher in milk samples obtained from camels kept indoors and machine milked. Protein content and ash were significantly ($p < 0.01$) higher in milk samples coming from grazing camels. Moreover, values of the pH and titratable acidity ranged from 6.3 to 6.8 and 14.4 to 21.6°D respectively. pH was the lowest ($p < 0.01$) in machine milked milk samples while titratable acidity was higher ($p < 0.05$) in milk samples from stabled and hand milked camels. Values obtained during this study were in the range of the values registered previously in milk samples from Tunisian camels except for fat content (Hammadi et al. 2010; Chamekh et al. 2020). Lower milk fat in hand milked camels could indicates a poor udder emptying as discussed previously. During early lactation and particularity milking in the presence of strangers, the milk ejection reflex could be altered as it was recorded in other dairy species (Bruckmaier and Wellnitz 2008; Cavallina et al. 2008; Andrea et al. 2015; Broucek et al. 2017). Moreover, the low fat content recorded during this work can aloso be related to differences between the richness of the morning and the evening milk in fat. Indeed, Hammadi et al. (2010) reported that the fat content increases from morning to evening (23.8 ± 1.7 and 48.3 ± 2.4 g/l, respectively) in manual milking and in mechanical milking (27.2 ± 1.8 and 42.6 ± 2.6 g/l, respectively).

Table 5. Effect of management and milking practice on milk quality.

	Stabling		Grazing
	Mechanical	Manual	Manual
Dry matter (g/L)	101.1 ± 10.8	103.4 ± 8.9	104.8 ± 13.8
Fat (g/L)	22.1 ± 4.6[a]	15.9 ± 3.3[b]	20.3 ± 6.6[a]
Protein (g/L)	29.4 ± 5.2[b]	32.7 ± 4.7[b]	35.5 ± 6.9[a]
Ash (g/L)	6.6 ± 0.8[c]	7.9 ± 0.6[b]	9.0 ± 0.4[a]
pH	6.4 ± 0.2[b]	6.6 ± 0.1[a]	6.6 ± 0.1[a]
Acidity (°D)	17.0 ± 1.7[ab]	17.8 ± 2.4[a]	15.0 ± 1.9[b]
Viscosity	2.7 ± 0.1	2.7 ± 0.2	2.7 ± 0.1

[a,b,c]Means in the same line with a different superscript letter are significantly different ($p < 0.05$).

The protein content was significantly higher in grazing camels' milk compared to stabling camels' milk. However, all recorded values remain higher than those reported by Hammadi et al. (2010) for intensively reared camels, but within the range of values reported by Ayadi et al. (2019) with 29 ± 3.2 g/l and 33 ± 1.1 g/l respectively for grazing and stabling camels. As expected, mineral content was significantly higher in milk samples from grazing camels since they grazed daily on halophyte pasture close the their farms.

Assessment of microbiological quality according to management and milking practice of raw dromedary camel milk

Results obtained by enumeration of different microbial flora of raw camel milk samples are shown in Table 6. The MTAF ranged from 7.4 10^3 to 4.3 10^6 cfu mL^{-1} with an average of 9.3 10^5 cfu mL^{-1}. Average count of total coliforms was 1.4 10^5 cfu mL^{-1} ranging between 2.7 10^3 and 5.3 10^5 cfu mL^{-1} and was significantly higher in machine milked camels. Yeast and moulds counts were 2.4, 1.7 and 5.4 10^4 cfu mL^{-1} respectively for milk samples coming from machine milked camels, hand milked camels under intensive system and hand milked camels in semi-intensive system. Enumeration results indicated a low levels of LAB less than 10^4 cfu mL^{-1} in most tested samples ranging between 2.2 10^3 and 2.4 10^4 cfu mL^{-1}. About half of the analysed samples contained higher levels of MTAF and total coliforms than the accepted threshold recommended by

Table 6. Microbial assessment and SCC of milk samples according to breeding system and milking practice.

	Stabling		Grazing
Bacterial load (10^4 cfu mL^{-1})	Machine	Manual	Manual
MTAF	193.0 ± 111.2	49.2 ± 16.9	70.5 ± 41.1
T. Coli	25.2 ± 14.3[a]	27.6 ± 10.2[a]	4.3 ± 1.3[b]
LAB	0.2 ± 0.0	0.6 ± 0.1	0.5 ± 0.2
Yeast and moulds	2.4 ± 0.3	1.7 ± 0.8	5.4 ± 1.4
S. aureus	72.5 ± 44.9[a]	7.2 ± 0.7[b]	0.1 ± 0.05[c]
SCC (10^4 cell/mL)	15 ± 5[ab]	7.5 ± 2.5[b]	23.6 ± 3.4[a]
S. aureus Prevalence	50 %	25 %	60 %
> AT* MTAF	50 %	0 %	10 %
> AT* Coliforms	50 %	25 %	60 %

MTAF: Mesophilic Total Aerobic Flores; T. Coli: Total Coliforms; LAB: Lactic Acid Bacteria; *S. aureus: Staphylococcus aureus*; AT*: Acceptability Threshold by INNORPI (2009).
[a,b,c]Means in the same line with a different superscript letter are significantly different ($p < 0.05$).

the INNORPI (2009) (National Institute for Standardisation and Industrial Property, Tunisia) in milk samples obtained from machine milked camels and about 60% of samples coming from manual milked camels in semi-intensive system had higher levels of total coliforms count.

Overall, the analysis of microbial quality and safety of camel milk suggested that camel milk from small-holder herds has high microbial contamination particularly when camels were machine milked. Although machine milking is recommended to ensure fast, complete and safe empting of the udder for camels (Atigui 2014), it is clear that poor hygienic practice could make the milking unit into a contamination vector. Indeed, during this study only 25% of the visited farmers used hot water and detergent to clean their milking equipments and about 25% used only water to rinse. The quality of the used water is also to be considered since most farms had no access to fresh clean water and they transported it in plastic containers or used metallic tanks. In addition, it seems that stabling increased significantly total coliforms count ($p < 0{,}05$). In fact, grazing camels were considered as ambulant herds where bedding area is periodically changed, consequently lowering the bacterial load of the bedding area which is also used as milking area in 75% of the studied farms. The milking area was also dusty, hence contamination from soil, from milkers' hands or camel coat during milking is also possible as reported by Musinga et al. (2008) and Kaindi et al. (2011). Although, all visited farms had acceptable clean milking location, we strongly recommend to avoid milking in the same bedding area and use a particular location for milking even for hand milking that should be built to be easily and effectively cleaned (washable surfaces and non-slippery floor). Contamination of raw camel milk with Coliforms might induce economical and public health hazards. These micro-organisms not only have the risk of pathogenicity but also, they decompose nutrients causing undesirable flavour and spoilage of raw milk and consequent qualitative losses of milk (Wanjala et al. 2018).

Prevalence of *S. aureus* also indicates poor hygienic status during milking and could have sever public health consequences. Approximately half of samples had positive results for *S. aureus*. Our samples indicated an average content of *S. aureus* equal to 180 10^3 cfu mL^{-1} with higher load in milk samples coming from machine milked camels. Our results were similar to those reported by Alaoui-Ismaili et al. (2019). In this study realised in southern Morocco, authors detected prevalence of *S. aureus* in 30% of raw camel milk samples from pastoral herds with an average of 232 10^3 cfu mL^{-1}. They also attributed the poor raw camel milk quality to poor hygiene conditions of hand milking in open air and to environmental conditions (strong winds, dust, and water scarcity). Ayoub et al. (2020) also reported similar results in raw camel milk collected in Matrouh region, Egypt. They revealed presence of *S. aureus* in 30% of collected samples at farm level. Even though, high prevalence of *S. aureus* have been related to occurrence of clinical and sub-clinical mastitis (Younan and Abdurahman 2004; Matofari et al. 2005), SCC was significantly lower in stabled camels than in grazing ones. This could be explained by a better health care in stabled herds and that contamination with these pathogens was mainly post harvest. In this study, SCC ranged between 50×10^3 cell/mL and 400×10^3 cell/mL. These results are comparable to those previously reported by Dahmani (2022) for camel milk samples from machine milked camels with an average of 150 10^3 cell/ml. Kaskous et al. (2021) suggested a cut-off point of 150 10^3 cells/ml for healthy udders. Nonetheless, Nagy et al. (2013) and Aljumaah et al. (2020) suggested a cut-off point for healthy quarters at about 400 10^3 cells/mL. Also, Guliye et al. (2002) found a mean SCC in infected and non-infected quarters of 414,954 cells/mL and 215,774 cells/mL respectively while Seligsohn et al. (2021) found a mean SCC in sub-clinical mastitis and healthy quarters of 1888,3 10^3 cells/mL and 282,7 10^3 cells/mL. Thus we considered that all tested samples came from healthy udder free from clinical and sub-clinical mastitis.

Evolution of camel milk quality at critical points along the market chain

Table 7 showed that overall mean of DM and ash content of camel milk did not differ significantly ($p < 0.05$) along the milk chain. Total solids in raw milk are an important indicator of nutritional value as it determines the levels of carbohydrates, fats, proteins, vitamins, and minerals. In the raw camel milk they are

Table 7. Quality evolution along the milk chain.

Milk	Camel	Bucket	Sale point	p Value
DM (g/L)	102.7 ± 11.1	109.9 ± 9.9	109.2 ± 14.9	0.153
Fat (g/L)	19.3 ± 7.6^{b}	23.9 ± 3.3^{ab}	28.3 ± 10.3^{a}	0.007
Protein (g/L)	31.9 ± 6.0^{b}	29.9 ± 9.9^{b}	37.7 ± 4.5^{a}	0.03
Ash (g/L)	7.6 ± 1.2	8.0 ± 0.4	7.8 ± 1.1	0.731
pH	6.6 ± 0.1^{a}	6.6 ± 0.1^{a}	6.2 ± 0.3^{b}	<0.0001
Acidity (°D)	16.9 ± 2.1^{b}	16.5 ± 2.4^{b}	25.3 ± 2.4^{a}	<0.0001
Viscosity	2.7 ± 0.1^{b}	2.6 ± 0.2^{b}	3.0 ± 0.7^{a}	0.042
> AT acidity	20.00 %^{b}	14.29 %^{b}	66.67 %^{a}	0.012

[a,b]Means in the same line with a different superscript letter are significantly different ($p < 0.05$).

supposed to range between 8 and 15% (Brezovečki et al. 2015). Fat and protein contents increased significantly along the value chain and they remained within the range reported by Kaskous (2019) and Karaman et al. (2021) for raw camel milk. However, pH and Dornic acidity decreased significantly along the milk chain ($p < 0.0001$). This reflects several physical and chemical alterations in the milk during storage. Although, milk at sale points is maintained at temperature less than 8 °C, over 66% of milk samples exceeded acceptance threshold of acidity. This can only indicates that the cold chain (<8 °C) was altered at previous points and that camel milk should be cooled starting from milking until it is reached the consumer. Some studies have shown that when camel milk is stored at room temperature (24–25 °C), severe alteration in physical and chemical characteristics were registered at 24 h post harvest (Omer and Eltinay 2009; Kaskous 2019).

In this study, all milk producers cooled their product at farm level, however milk purchased at sale point showed a significant acidification due to a significant increase in total bacterial count as shown in Figure 1. The average generation time of micro-organisms was around 20 to 30 min under optimal growth conditions (temperature: 25 to 35 C° and PH 6.65) (Kaskous 2019), which indicates that a short alteration in the cold chain could lead to severe alteration in milk bacterial load and consequently alteration in milk physical and chemical proprieties.

In Tunisia, almost all camel milk is consumed raw or fermented without any heat treatment (Hamouda et al. 2022), as it is the case in north African countries (Elhosseny et al. 2018; Alaoui-Ismaili et al. 2019), Arabian peninsula (Omrani et al. 2015; Elhaj and AlSobeai 2018), Sudan (Abdelgadir et al. 2008; Kumar et al. 2016) and most camel milk producing countries.

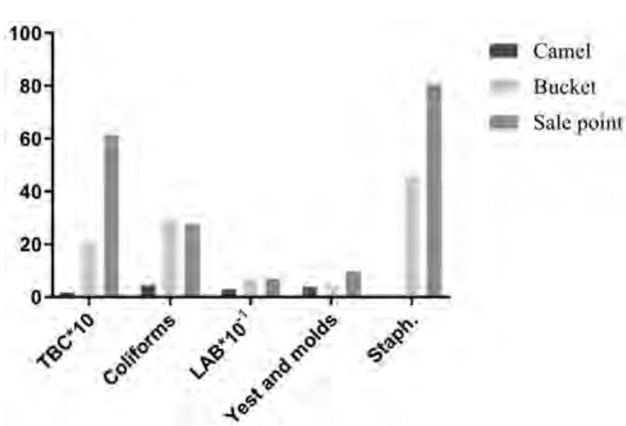

Figure 1. Microbial evolution at critical points along the market chain. TBC: total bacterial count; LAB: lactic acid bacteria; *Staph.: Staphylococcus aureus.*

Thus, it is important to highlight the bacteriological quality and the safety of raw camel consumption. It is clear that, many interactive factors contributed to poor hygienic quality of the camel milk sold at the markets (Figure 1 and Table 8). Younan and Abdurahman (2004) as well as Kaindi et al. (2011) reported several risk factors including little consideration to hygiene during milking, storage and transporting, pooling of morning and evening milk at farm level and bulking milk from different camel herds. This might be due to the differences in initial contamination originating from the udder surface, quality of water used for cleaning milking tools and the time lapse from production to marketing. Milk collected directly from udder was found with better bacteriological quality than milk in the milking bucket and the one collected from market. This might be due to the traditional methods of distribution and transportation of milk including; use of easily contaminated and hard to clean container, long transit time to markets with frequent opening of containers for retail or milk transfer as reported by Abera et al. (2016).

Sanitation problems and keeping the cold chain were identified as the biggest challenge due to the lack of water and cooling facilities along the milk value chain. Thus, public health concerns may be raised with improper handling of milk along the marketing chain. Also, the lack of heat treatment of camel milk may foster the action of spoilage and pathogenic micro-organisms in milk (Mwangi et al. 2016; Hamouda et al. 2022). However, at this microbial load, it is advisable to use preservation methods like pasteurisation or strict control of the cold chain to enable transportation to distant market channels. Facilities for these methods are hardly available in pastoral environment or smallholder farms. Thus a strict regulations and governmental control should be instated to ensure better milk quality and limit public health hazards due to raw camel milk consumption. Indeed, Smits et al. (2022) highlighted the flourishing camel milk market, yet they expressed some concerns about public health risks and legislation of raw camel milk trades.

Table 8. Prevelance of *S. aureus* and bacterial contamination in different sampling points.

Milk	Camel	Bucket	Sale point	*p* Value
S. aureus Prevalence	0 %	71.43 %	100 %	<0.0001
$>$ AT MTAF	0 %	42.86 %	100 %	0.001
$>$ AT Coliforms	36.36 %	100 %	100 %	0.011

MTAF: Mesophilic Total Aerobic Flores; *S. aureus: Staphylococcus aureus*; AT: Acceptability Threshold by INNORPI.

As shown in Table 8, all samples from camels' udders did not exceed acceptance threshold for MTAF and *S. aureus* was not detected at udder level while bacterial contamination was detected at farm level in the milking bucket and increased to 100% of milk samples purchased from the market. This is associated with post harvest handling of the milk. Indeed, intense manipulation of small quantities of milk using several containers of small capacity difficult to clean at the primary collectors, transportation and handling without cooling were reported (Kaindi et al. 2011). In marginal areas, food production, processing and marketing is highly fragmented and rely on on small producers and their primer knowledge. Most of the milk goes through many handler which increases the risk of exposing the food to unhygienic environments, contamination and adulteration (Bachmann 1992).

Conclusions

Results from the present study clearly indicated that the use of machine milking technique is still limited and it was associated with a higher bacterial charge. The alterations of physical proprieties, microbial quality and safety of raw camel milk at various levels of value chain were observed mainly at farm and sale points levels. High bacterial load and *S. aureus* prevalence in raw camel milk indicated that milk hygiene practices and the cold chain should be respected and improved along the milk chain production in order to guarantee quality that meets the needs of the consumer. Thermal treatment of milk is strongly recommended before consuming the camel milk. Finally, the government should control this new emerging sector and take measures to encourage breeders to take extra care of the hygienic practices.

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Ethical approval

The work did not involve experimental animals or human subjects, it was therefore, exempted from institutional ethical clearance.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

Datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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