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SOME ASPECTS OF CAMEL MILK AND ITS SAFETY FOR HUMAN CONSUMPTION-AN OVERVIEW

Shehadeh Kaskous[1] and Michael W. Pfaffl[2]

[1]Department of Research and Development, Siliconform, Schelmengriesstrasse 1, 86842 Türkheim, Germany
[2]Department of Animal Physiology and Immunology, School of Life Sciences, Technical University of Munich, 85354 Freising, Liesel-Beckmann-Straße 1, Germany

ABSTRACT

Camel milk is in high demand in many countries around the world. There appears to be increasing awareness of the use of camel milk in human diet. Therefore, the aim of this study was to determine the importance of camel milk and its safety for human consumption. Camel milk contains numerous antimicrobial components and protective factors, making it a unique milk compared to the milk of other lactating animal species. Camel milk production varies between 1000 and 12000 kg during the lactation period of 8 to 18 months, with large differences between geographical regions, feeding and husbandry conditions. The composition of camel milk is 2.5-5.5% fat, 2.2-4.5% protein, 2.5-5.5% lactose, 0.7-1.0% ash and 8.0-15% dry matter. To increase milk production for each camel and improve the quality and safety of raw camel milk, the use of a suitable milking machine such as StimuLactor is necessary. In addition, correct husbandry, feeding and hygiene measures must be considered. In conclusion, regarding the importance of camel milk and the associated related health benefits of its bioactive ingredients, improvements in milking hygiene, milk storage and transport conditions are required to ensure the quality of camel milk meets consumer needs.

Key words: Camel, human milk, milking machine, milk yield

Camel milk is one of the most important nutritional sources for the population in many arid and semi-arid areas of the world, as it contains almost all the vital nutrients needed in dry climate. The camel population in the world is approximately 35 million, about 95% of which are dromedaries (FAO, 2022). Camel milk yield varies between 1000 and 12000 kg during the lactation period of 8 to 18 months (Boujenane, 2020; Swelum *et al,* 2020). However, the amount of milk per lactation depends on many factors such as breed (Type), animal health, lactation stage, lactation number, living conditions and season (Yamina *et al,* 2013; Chamekh *et al,* 2020; Swelum *et al,* 2021; Boudalia *et al,* 2023). Camel milk was named as the most valuable product (Davati *et al,* 2015) and it is known as "white gold of the desert" (Wernery, 2006). However, camel milk contains numerous minor components that have special bioactive properties (Kaskous and Pfaffl, 2017; Swelum *et al,* 2021; Oselu *et al,* 2022). These are present in significant concentrations and are extremely important and beneficial to human nutrition and health (Kaskous, 2016). Therefore, camel milk is usually consumed as a fresh or naturally fermented product and is therefore not pasteurised (Mehari *et al,* 2007; Matofari *et al,* 2013; Abera *et al,* 2016; Mwangi *et al,* 2016; Serda *et al,* 2018). But camel milk is an excellent food for the growth of microorganisms (Zangerl, 2007; Matofari *et al,* 2013) and non-heat-treated milk and raw milk products are the main cause of diseases caused by pathogens (De Buyser *et al,* 2001; Smits *et al,* 2023). It is noteworthy that the milk from a healthy udder is usually "sterile" (Johnson *et al,* 2015) because the camel udder is protected by a variety of defence mechanisms such as innate or specific immunity as well as physiological peculiarities and is only contaminated with germs when it passes through the teat canal (Zangerl, 2007). In addition, the germs that get into the milk come from the udder-and teat-surface, the stall, the air, the water, the feed, the milker, and the milking equipment. Contamination of raw camel milk can be very high if udder health is not checked, plastic containers are used during milking and storage, hygiene measures are not carried out during milking, and water is not available to clean the teat and udder before milking (Mulwa *et al,* 2011; Ismaili *et al,* 2019; Atigui *et al,* 2023). During milk transportation, especially when the route is long, and poor and the milk is not refrigerated, the microbial content of the milk multiplies rapidly (Mulwa *et al,* 2011; Ismaili *et al,* 2019). Due to the many contaminated factors, it has been shown that the poor hygiene status in the

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production and handling of camel milk as well as the lack of low-cost post-harvest technologies mean that camel milk has lost its potential to improve the living conditions of the camel farmer (Matofari *et al,* 2007; Ismaili *et al,* 2019; Hassen *et al,* 2022) and this limitation leads to losses in quality and quantity after harvest, especially physical-chemical and microbiological deterioration of the milk (Odongo *et al,* 2016; Ismaili *et al,* 2019; Atigui *et al,* 2023). The production of hygienically perfect, ready-to-process milk places high demands on the camel farmer. This means optimal animal husbandry, animal care, good feeding, ideal milking machines and cooling of the milk during storage and transport to deliver consistently high-quality milk to the consumer. To achieve this goal, the transition from traditional production systems to intensive production systems must be accelerated. In the following some aspects of camel milk and its safety for human consumption are presented and discussed.

Composition of camel's milk

The composition of camel milk is different from those of other lactating animals' species particularly due to its protein composition, milk fat structure and mineral and vitamin content (El-Hatmi *et al,* 2015; Abduku and Eshetu, 2024), but it contains all the important nutrients (Farah, 2011; Kanca, 2017; Boujenane, 2020; Swelum, 2021; Lajnaf *et al,* 2023). Camel milk contains the following components: 2.2-4.5% protein, 2.5-5.5% fat, 2.5-5.5 lactose, 0.7-0.95% ash and 8.0-15% total dry matter (El-Hatmi *et al,* 2006; Konuspayeva *et al,* 2009; Kaskous *et al,* 2012; Ali *et al,* 2019; Ismaili *et al,* 2019; Roy *et al,* 2020; Seifu 2022; Kaskous, 2023). However, the composition varies greatly and depends on various factors, such as the breed (type), individual, husbandry and feeding condition, age, milking interval, stage of lactation, number of lactations, season, management, and udder health (Wernery, 2007; Shuiep *et al,* 2008; El-Hatmi *et al,* 2015; Jrad *et al,* 2015; Patel *et al,* 2016; Ismaili *et al,* 2019; Swelum *et al,* 2021; Behrouz *et al,* 2022; Kraimia *et al,* 2024). In general, camel milk has lower amounts of fat, protein, and lactose compared to bovine milk (Smits *et al,* 2011; Konuspayeva *et al,* 2011; Arab *et al,* 2014; Alhaj *et al,* 2022).

Camel milk Proteins

Camel's milk is a rich source of proteins with potential anti-microbial and protective activity (Kaskous and Pfaffl, 2017; Mohamed *et al,* 2020; Lajnaf *et al,* 2023). It was observed that camel milk has 21 different amino acids compared to 18 amino acids in bovines. Such amino acids are the synthesis basis of all proteins in camel milk (Fig 1). Practical results have shown that the average protein content of camel milk under European conditions was 3.34% in the Netherlands (Smits *et al,* 2011), 2.28% in Germany (Kaskous, 2019) and 2.39% in Switzerland (Kaskous, 2023), while the average protein content in camel milk outside Europe was 3.1% (Konuspayeva *et al,* 2009; Al haj and Al Kanhal, 2010). In general, the protein content of camel milk ranges between 2.2 and 4.5% (Konuspayeva *et al,* 2009; Yadav *et al,* 2015; Kula and Dechasa, 2016; Patel *et al,* 2016; Swelum *et al,* 2021; Seifu, 2022). This difference is due to environmental conditions and the availability of food and water for the lactating camels (Yamina *et al,* 2013; Ismaili *et al,* 2019). Camel milk proteins appear as: Casein, whey proteins, fat globule membrane proteins. However, the average casein content and whey protein content of camel milk vary between 1.9 and 2.3% and 0.7 and 1.0%, respectively (Farah, 2011). Caseins make up the highest proportion of the protein fraction in camel milk (Hamed *et al,* 2012; Swelum *et al,* 2021). This represents 65-70% of total proteins compared to an average of 83% in bovine milk (Khaskheli *et al,* 2005; Frister, 2007; Hamed *et al,* 2012). Like cow's milk, casein in camel milk consists of four fractions. These are αs1, αs2, β and k-casein (Al haj and Al kanhal, 2010; Abbas *et al,* 2013). However, camel milk contains more β-casein (75%) than α-casein (21%) of total casein, compared to cows' milk, which contains approximately the same content of β-casein and α-casein (36 and 38%) (Devendra *et al,* 2016; Kappeler *et al,* 2003; Yirda *et al,* 2020). Interestingly, camel milk contains very little k-casein (3.5%) of total casein, compared to the k-casein content (13%) in cow's milk (Devendra *et al,* 2016; Mbye *et al,* 2022). It was observed that whey proteins in camel milk constituted about 30-35% of total protein (Khaskheli *et al,* 2005; Jilo and Tegegne, 2016; Dugassa, 2021; Vincenzetti *et al,* 2022). Camel milk as human milk does not contain β-Lactoglobulins (El-Hatmi *et al,* 2007; Elagamy *et al,* 2009; Kaskous and Pfaffl, 2017; Rahmeh *et al,* 2019). Therefore, α-lactalbumin is the main whey protein in camel milk (Wernery, 2007; Redington *et al,* 2016; Lajnaf *et al,* 2023). Camel milk contains other important components of whey proteins such as serum albumin with a variation of 2.9 and 13.8 g/l (El-Hatmi *et al,* 2006) and lactoferrin with 227-229 mg/l (Konuspayeva *et al,* 2007; Kaskous *et al,* 2012). In addition, several reports have shown that camel milk has higher immunoglobulins (0.72 g/l) than cow's milk (0.47 g/l) (Kaskous and Pfaffl, 2017).

Camel milk fat

The fat content of camel milk varies between 2.5 and 5.5% depending on the nutritional status, stage of lactation, breed and the season of the year (Mal *et al,* 2006; Yamina *et al,* 2013; Devendra *et al,* 2016; Kaskous, 2019; 2023; Abduku and Eshetu, 2024). The fat globules in camel milk are the smallest among all ruminants ranging from 0.1 to 18 micrometers in diameter (El-Zeini, 2006), and these do not naturally aggregate due to the absence of agglutinin (Khalesi *et al,* 2017). 96% of the fat in camel milk is triacylglycerol (Nikkhah, 2011; Dugassa, 2021). Compared to cow's and buffalos' milk, camel milk fat contains lower concentrations of short-chain fatty acids and higher concentration of long-chain fatty acids (C_{14}-C_{18}) (Abu-Lehia, 1989; Konuspayeva *et al,* 2008; Abbas *et al,* 2013; Sara *et al,* 2022). The saturated fatty acid (SFA) in camel milk varied between 50% (Bactrian camel milk) and 60% (dromedary camel milk) of total fatty acids (Rahmeh *et al,* 2019) and about 65% of total fatty acids according to Wang *et al* (2011) and Oselu *et al* (2022). However, the monounsaturated fatty acids (MUFA) in dromedary camel milk were 56-80% of total fatty acids (Medhammar *et al,* 2012). In addition, the proportion of unsaturated fatty acids in camel milk was between 35 and 50% of the total fatty acids (Izadi *et al,* 2019). It is noteworthy that the proportion of unsaturated fatty acids in the fatty acid pattern of camel milk in the intensive production system was 43.1% (Stahl *et al,* 2006). In addition, the fat content in camel milk was found to be highly dependent on the stage of lactation, with the highest concentration occurring in the first three months of lactation (34.67±1.30 g/l), compared to the concentration in the middle (27.40±5.69 g/l) and the end of lactation (29.12±2.83 g/l) (Kraimia *et al,* 2024).

Camel milk lactose

The lactose content in camel milk is not stable, although it is involved in the osmotic pressure in the udder. It is noteworthy that a different mechanism exists in camels, as regular feeding and water are not available in many regions of the world. Therefore, different concentrations of lactose have been found in camel milk. Milk lactose content was observed to be 4.3 ±0.2% higher in camels deprived of water for four days compared to 4.1±0.2% for 16 days (Bekele *et al,* 2011). These results illustrate that the variation in lactose content in camel milk is mainly related to water intake and the type of feed consumed (Al haj and Al kanhal, 2010; Kula and Dechasa, 2016). In general, the lactose content in camel milk varied between 2.5% and 5.5% (Khan and Iqbal, 2001; Konuspayeva *et al,* 2009; Devendra *et al,* 2016; Faraz, 2020; Dugassa, 2021; Alhaj *et al,* 2022; Karaman *et al,* 2022). In addition, lactose content in camel milk was observed to be high in the first months of lactation (42.5 g/l), followed by a significant ($P<0.05$) decrease at the end of lactation (38.35 g/l) (Kraimia *et al,* 2024). At this point, it must be said that the significant change in lactose concentration in camel milk is due to the health of the udder. It is known that in clinical or subclinical mastitis, the lactose content of the milk decreases and new synthesis is reduced (Schulz, 2003). New research has shown that the average lactose content in the milk of a healthy camel udder was around 4.09±0.03% after using new "StimuLactor" milking machines on a practical farm in Switzerland (Kaskous, 2023).

Camel milk vitamins and minerals

Studies on the vitamin content of camel milk have been carried out for a long time (Sawaya *et al,* 1984; Farah *et al,* 1992). Stahl *et al* (2006) found that fresh dromedary milk contains less vitamin A, E, B_1 and β-carotene than cow's milk. An interesting aspect: The vitamin C content in camel milk (34.16 mg/l) was 2 to 3 times higher than in cows' milk (Farah *et al,* 1992) and 6 times higher than in human milk (Gizachew *et al,* 2014). However, the vitamin C content of camel milk was between 24 and 52 mg/kg and was therefore, 2-4 times higher than that of cow's milk (15±6.3 mg/l) (Mehaia, 1994; Stahl, 2005; Kamal and Karoui, 2017). The high vitamin C content in camel milk makes nutritional sense because fruits and vegetables are rarely part of the human diet in dry areas and intake of vitamin C *via* camel milk can help prevent vitamin deficiencies in humans. It has also been found that the lower carotene content makes the colour of camel milk whiter compared to cow's milk (Stahl *et al,* 2006; Devendra *et al,* 2016). In addition, studies using Bactrian camel milk showed that camel milk was rich in vitamin D and riboflavin and consumption of two cups daily provided 160% of the recommended dietary intake of vitamin D (5 µg/day) and riboflavin (0.5 mg/day) (Wijesinha-Bettoni and Burlingame, 2013).

Furthermore, research has shown that camel milk is rich in minerals such as calcium, phosphorus, sodium, potassium, chloride, iodine, and magnesium (Shamsia, 2009; Gizachew *et al,* 2014; Aljumaah *et al,* 2012; Alhadrami and Faye, 2016). The average contents of Ca, K, Mg and Na in camel milk were 1.47±0.38, 0.98±0.24, 0.07± 0.01, and 0.65±0.11 g/l, respectively (Jrad *et al,* 2015). However, the average ash content in camel milk varied between 7.5 and 8.8 g/l (Jrad *et al,* 2015; Abdel Galil *et al,* 2016). It is noteworthy that the content of iron, zinc and copper in camel milk was higher than in cows' milk (Singh *et al,* 2006). It should be noted that many factors such as breed (type), diet, water consumption and analytical methods can affect the mineral content of camel milk (Mehaia *et al,* 1995; Haddadin *et al,* 2008). A new study has shown that the season can have an impact on the minerals in camel milk (Kraimia *et al*, 2024) (Table 1).

Safe raw camel milk for human consumption

In many countries, particularly in Africa and the Middle East, the consumption of raw camel milk has increased and is often considered as a "health food" with positive effects on digestion, the immune system and for treatment of various diseases (Gonfa *et al,* 2001; Seifu, 2007; Zaitlin *et al,* 2013). According to an online survey of 852 consumers conducted in the United Arab Emirates (UAE), about 58.4% consumed unpasteurised camel milk (Cheikh Ismail *et al,* 2022). The reason for consuming unpasteurised camel milk was that this milk strengthens the immune system and has higher nutritional content (Smits *et al,* 2023). Therefore, raw camel milk was used to treat, alleviate, or prevent health conditions such as diabetes, autism, cancer, dementia, allergies, and parasites (Kaskous, 2016). In Ethiopia, most of camel milk is consumed in the raw state without any heat treatments (Eyassu, 2007; Mehari *et al,* 2007; Roess *et al,* 2023). In the Arabian Peninsula, consumption of unpasteurised camel milk is also common (Omrani *et al,* 2015). Furthermore, fresh and fermented camel milk has been also used in India, Russia, and Sudan for human consumption as well as for treatment of a series of diseases (Kumar *et al,* 2016). Unpasteurised sour camel milk and fresh cow's milk form the core of the Somali diet (Seifu, 2007; Sadler and Catley, 2009; Carruth, 2014). On the other hand, some countries like UAE, Australia and USA warned that camel raw milk was not generally recognised as safe or effective for the therapeutic uses. However, consuming raw or unpasteurised dairy products poses several known risks, especially if refrigeration is not ensured (Zaitlin *et al,* 2013; Carruth *et al,* 2017). The Food and Drug Administration (FDA) in USA warned that if the camel farmer was going to market their product as a "drug", they needed to get federal approval, which would require the farm to provide scientific data demonstrating the safety and effectiveness of their product. Moreover, FDA warned that a consumption of raw camel milk is a health risk, because it is associated with foodborne illness caused by pathogens including *Campylobacter, Escherichia coli, Listeria, Brucella, Staphylococcus* and *Salmonella* (Yamina *et al,* 2013; Swinburne, 2017; Wernery *et al,* 2017; Dadar *et al,* 2019). Based on the observation of Spargue *et al* (2012) that brucellosis a bacterial disease caused by various infectious Brucella

Table 1. Some factors that affect the concentration of minerals in camel milk, according to Kraimia *et al* (2024), with some changes.

Factors		Minerals in camel milk					
		Na (g/l)	K (g/l)	Ca (g/l)	Mg (g/l)	I (g/l)	P (g/l)
Day	Morning	0.39	2.44	1.90	0.07	0.13	0.70
	Evening	0.45	2.39	1.73	0.07	0.13	0.83
	P<0.05			*			**
Stage of lactation	Beginning	0.43	2.63	1.51	0.07	0.15	0.72
	Middle	0.44	2.35	1.67	0.07	0.14	0.65
	End	0.41	2.37	1.75	0.07	0.12	0.69
	P<0.05					*	
Lactation number	1	0.49	2.28	1.67	0.07	0.13	0.63
	2-6	0.46	2.19	1.48	0.07	0.12	0.78
	>6	0.44	2.40	1.66	0.08	0.11	0.66
	P<0.05						
Season	Winter	0.46	2.26	1.48	0.07	0.12	0.66
	Spring	0.39	2.44	1.90	0.07	0.13	0.70
	Summer	0.45	2.38	1.55	0.08	0.15	0.68
	Fall	0.52	2.28	1.61	0.08	0.13	0.77
	P<0.05	***		***	***	**	

*: P<0.05; **: P<0.01; ***: P<0.001

species and is transmitted through both close contact with camels and consumption of raw camel milk. However, camel brucellosis has been diagnosed in all camel-rearing countries except Australia and mainly depends on the management system (Wernery, 2014). Zimmermann (2016) reported that one of the primary risks of camel's milk is consumed in unpasteurised form. Reviewed by Roess *et al* (2023) found that consumption of days-old unrefrigerated raw camel milk was significantly associated with gastrointestinal symptoms. The Saint Louis Institute for conservation medicine studied the consumption of camel milk in northern Kenya, where around 10% of people drink unpasteurised camel milk, exposing themselves to a few animal-based pathogens. The study found a higher prevalence of pathogenic bacteria in raw camel milk than in sheep and cattle milk. Furthermore, Musinga *et al* (2008) found that contaminations of raw camel milk in Kenya can occur along the chain from producers to final consumers and the consumption of raw camel milk should be of major concern to public health. Research in Saudi Arabia and Morocco found that raw camel milk samples were contaminated due to poor handling practices and hygiene conditions (El-Ziney, 2007; Alaoui Ismaili *et al,* 2019). Matofari *et al* (2013) found in Kenya that salmonella enteric occurrence along the camel milk chain had an incidence of 13% with the highest being in the farm environment. The sources of this pathogen may constitute the risk factors that are associated with its prevalence in the environment. However, milk from individuals without clinical or subclinical mastitis may also contain mastitis-causing pathogens, and other factors, such as soil, water, and pastoralists (Elmoslemany *et al,* 2010). Farm management practices and seasonality have also been shown to have a significant impact on the contamination of raw camel milk (Shuiep *et al,* 2008; Smits *et al,* 2023). The control of raw camel milk is an important issue for human consumption (Alebie *et al,* 2021). In fact, pasteurisation is a good preservation method to produce high-quality milk.

Raw camel milk and udder inflammation

Camel udder can get clinical or subclinical mastitis, like other dairy animals (Alebie *et al,* 2021; Rahmeh *et al,* 2022). A high percentage of subclinical mastitis in camels is reported by several authors (Obeid *et al,* 1996; Almaw and Molla, 2000; Wanjohi *et al,* 2013; Niasari-Naslaji *et al,* 2016) and the values varied between 15 and 70% (Bhatt *et al,* 2004; Abera *et al,* 2010; Seifu and Tafesse, 2010; Alamin *et al,* 2013). In general, 46% of the global camel population suffers from mastitis (Aqib *et al,* 2022). It was shown that mastitis pathogens of the dromedary are the same as cultured from the mammary gland of bovines and these are *Streptococcus agalatiae, Staphylococcus aureus, Coagulse- negative Staphylococcus, Streptococcus bovis, Streptococcus uberis, Streptococcus dysagalactia*e (Wernery *et al,* 2008). In the traditional husbandry systems, poor management, and unhygienic milking lead to mastitis in camels (Obeid *et al,* 1996; Almaw and Molla, 2000). The results from Golestan province in Iran have shown that out of 243 camel milk samples from individual quarters (95 milking camels), 18.1% were subclinical mastitis and somatic cell count values beyond 306 x 10^3 cells/ml could be considered as subclinical mastitis in camel (Niasari-Naslaji *et al,* 2016). Bekele and Molla (2001) reported that, out of 152 camels in Afar Region, north-eastern Ethiopia examined, 19 (12.5%) were diagnosed as clinical mastitis cases based on clinical signs and bacteriological examinations. The main mastitis pathogens isolated were *Staphylococcus aurous, coagulate negative staphylococci, Streptococcus agalactiae, S. dysgalactiae,* and other species of *streptococci, Pasteurella haemolytica* and *E. coli*. Similar results have been shown by Wanjohi *et al* (2013) that subclinical mastitis was prevalent in dromedary camels of two districts of north-eastern province of Kenya, and that Gram-positive cocci (*Staphylococcus* and *Streptococcus*) were the dominant mastitis pathogens isolated. Other isolated bacteria were found as *Klebsiella/Enterobacter, Escherichia coli* and *Bacillus*. In addition, *Staphylococcus aureus, Streptococcus agalactiae, Escherichia coli* and *Corynebacterium bovis* were the main pathogens of camel mastitis (Aqib *et al,* 2022). Rahmeh *et al* (2022) found that the genera *Staphylococcus, Streptococcus, Schlegelella,* unclassified *Enterobacteriaceae, Lactococcus, Jeotgalicoccus* and *Klebsiella* were abundant in mastitis milk compared to healthy samples. Abdel Gadir Atif *et al* (2006) have performed comparison of California mastitis test (CMT), somatic cell counts (SCC) and bacteriological examinations for detection of camel mastitis in Ethiopia. A total of 956 quarter milk samples from 253 camels were detected. 59.7% quarter milk samples had microorganisms. A positive correlation was found between CMT scores and bacteriological classes ($P<0.001$) and SCC ($p<0.001$). Detection of subclinical mastitis in dromedary camels using somatic cell counts, California mastitis test and udder pathogen was also done in Saudi Arabia (Saleh and Faye, 2011). A total of 120 quarter milk samples from 30 clinically healthy dromedary camels were cultured. SCC varied from 9000 to 2 000.000

cells/ml with an average of 125000. Intramammary infections were present in most of examined quarter milk samples. The current review by Aqib *et al* (2022) showed the forms of camel mastitis. Clinical mastitis is characterised by hardening and swelling of the udder, pain on palpation, and visible changes in the colour and texture of the milk. Subclinical mastitis is inflammation without obvious signs (El Tigani-Asil *et al,* 2020) that can be detected by CMT, SCC and microbiological examination. It is noteworthy that an increase in SCC above the physiological value not only indicates a problem with udder health, but also leads to reduced milk yield, a change in milk composition, an impairment of milk processing and a change in the bioactive ingredients of camel milk (Kaskous *et al,* 2021)

Based on that, the disease has been reported in numerous camel-producing countries in Africa and Asi (Aqib *et al,* 2022). The following table presents the results of some works on contaminated udder quarters with microorganisms (Table 2).

In Sudan, raw camel milk samples were collected and the isolated aerobic bacteria (115 isolates) were identified as Gram-negative (85.26%), while 14.73% of samples were Gram-positive. The authors emphasised that raw camel milk is a source of many bacteria which may lead to health hazards for men (Elhaj *et al,* 2014). In the southern province of Jordan, raw camel milk samples were collected from 90 dromedary camels. About 21% of the camels revealed clinical signs of mastitis. The most predominant bacteria isolates were *Staphylococcus aureus*, *Streptococcus* spp. *Micrococcus* spp. and *Corynebacterium* spp. (Hawari and Hassawi, 2008). The microbial quality of raw camel milk in United Arab Emirates was investigated, 50 samples were analysed for: Aerobic plates count, total coliform, total *Staphylococcus aureus*, total yeast, and Mold. The results indicated that the mean value of aerobic plate count was 1.8×10^5 cfu/ml, the mean value of total coliform was 6.8×10^{-1}, the mean value of *Staphylococcus aureus* was 1.2×10^3, and the yeast mean value was 4.1×10^{-1} cfu/ml (Omer and Eltinay, 2008). Furthermore, it should also be noted that the calf may be a source of prevalence of microbes in camel milk. So, in many countries, the calf will have their mother suckle to induce the milk ejection reflex. But the calf may compromise the udder hygiene since

Table 2. Raw camel milk with subclinical and clinical mastitis in some countries.

Country	Number of milk samples (quarter or udder)	Positive samples of subclinical or clinical mastitis (%)	References
Egypt	90 (udder)	87.78	Asfour and Anwer (2015)
Ethiopia	956 (quarter)	59.7%	Abdel Gadir Atif *et al* (2006)
Ethiopia	205 (quarter)	37.6%	Abdurahman (2006)
Ethiopia	145 (udder)	29%	Abera *et al* (2010)
Ethiopia	47 (udder)	76.60%	Abera *et al* (2016)
Ethiopia	543 (quarter)	63%	Bekele and Molla (2001)
Ethiopia	34 (udder)	5.88 %	Hadush *et al* (2008)
Ethiopia	374 (quarter)	8.9%	Alebie *et al* (2021)
Iran	243 (95)	18.1%	Niasari-Naslaji *et al* (2016)
Jordan	90 (udder)	21%	Hawari and Hassawi (2008)
Kenya	86 (quarter)	81.4%	Guliye *et al* (2002)
Kenya	107 (udder)	66%	Matofari *et al* (2013)
Kenya	66 (udder)	Most of examined quarter milk samples	Odongo *et al* (2016)
Kenya	380 (quarter)	44.5%	Toroitich *et al* (2017)
Kenya	207 (udder)	23%	Younan *et al* (2001)
Kenya	384 (udder)	61.2%	Wanjohi *et al* (2013)
Kuwait	25 (udder)	36%	Rahmeh *et al* 2022
Saudi Arabia	120 (quarter)	Most of examined quarter milk samples	Saleh and Faye (2011)
Saudi Arabia	740 (quarter)	33 % of tested quarters had subclinical mastitis based on CMT	Al Jumaah *et al* (2012)
Sudan	160 (udder)	71.9%	Elhaj *et al* (2014)
Sudan	391 (quarter)	43.5%	Abdurahman *et al* (1995)

after suckling no cleaning of the udder before milking is done (Noor *et al,* 2013). Several lines of evidence suggest that the risk factors for camel mastitis were severe tick infestation, teat injuries, poor milking hygiene and physiological disorders (Ahmad *et al,* 2012; Aqib *et al,* 2022). Finally, the negative effects of mastitis on camel owners include a reduction in milk production, deterioration in milk quality, a decrease in milk price due to high SCC, loss of milk due to antibiotic treatment, and increased animal care costs (Hertl *et al,* 2010; Tuteja *et al,* 2013).

Using a milking machine to obtain safe raw camel milk for consumption.

Usually, camels are milked by hand in most countries of the world in traditional farming systems (Bekele *et al,* 2002; Alhadrami and Faye, 2016; Atigui *et al,* 2023). The introduction of machine milking makes only slow progress and is limited to intensive dairy camel farms in a few countries (Kaskous and Fadlelmoula, 2014). To improve the quality and the safety of raw camel milk, machine milking must be used instead of hand milking (Hammadi *et al,* 2010; Nagy and Juhasz, 2016; Kaskous, 2018a, 2019). Saleh *et al* (2013) showed a clear difference between two milking methods in terms of udder health and milk quality. Therefore, microbiological contamination was higher in farms with hand milking than in farms with machine milking (Table 3).

Table 3. Bacteriological finding of camel milk samples in two farms with different milking methods (Saleh *et al,* 2013).

Parameters	Farm with machine Milking	Farm with hand milking
Number of Camels	14	14
Duration of the investigation	6 months after calving	6 months after calving
Total samples	84 (100%)	84 (100%)
Uninfected samples	65 (77.4%)	53 (63.1)
Coagulase-negative Staphylococci	15 (17.8%)	22 (26.2%)
Staphylococcus aureus	-	3 (3.6%)
Micrococcus	4 (4.8%)	6 (7.1%)

However, it must be noted that many milking machines used do not succeed in completely emptying the udder. The amount of residual milk after machine milking was high (up to 30% or even more) (Kaskous, 2018b). Review by Ayadi *et al* (2013) clearly showed that low fat levels were observed in milk during mechanical milking, indicating incomplete milk letdown. In addition, it has also been found that improper use of the milking machine, especially improper use of liners, can damage the camel's udder, lead to oedema, and promote the colonisation of *Staphylococcus aureus* during the time of machine milking (Juhasz and Nagy, 2008). Results from Tunisia have shown, that the use of machine milking in the field was associated with higher milk yields, but also resulted in increased microbial contamination compared to hand milking (Atigui *et al,* 2023). Kaskous (2023) has shown reverse results that no pathogenic bacteria were detected in the milk produced after using the milking machine (StimuLactor). Improper use of the milking machine is known to have negative effects on udder health as the udder cannot be completely emptied (Kaskous and Pfaffl, 2023). As a result, the remaining milk after milking can serve as a substrate for pathogens and increase the risk of mastitis (Bruckmaier and Wellnitz, 2008). Therefore, completely emptying the udder during milking promotes milk synthesis and secretion and ensures that the udder remains healthy.

As the market is looking for a suitable milking machine for camels, a special modern milking machine called "StimuLactor" was developed by Siliconform, Germany in 2018, which has been used in practice since then (Fig 2). This milking machine for camels was necessary to enable rapid and complete milk extraction during milking and to maintain udder health. A field study showed that the udder remained healthy and completely emptied after using the "StimuLactor" milking machine (Kaskous, 2019), since this milking machine has been adapted to the anatomical, morphological, and physiological characteristics of the camel's udder.

Training on the milking machine is an important point because by getting the camels used to machine milking, their stress behaviour is reduced, their milk production is increased and the milking time is normalised (Brahmi *et al,* 2024).

Finally, maintaining healthy udders and teats during milking is a key component of an effective milking machine to achieve good and higher quality milk production by preventing mastitis and maintaining animal welfare. In this way, we can help provide consumers with good and safe camel milk.

Factors affecting safe raw camel milk after harvest

Raw camel milk is a natural food that can be contaminated with microbiota in the chain from the milking to the consumer as the milk is very good

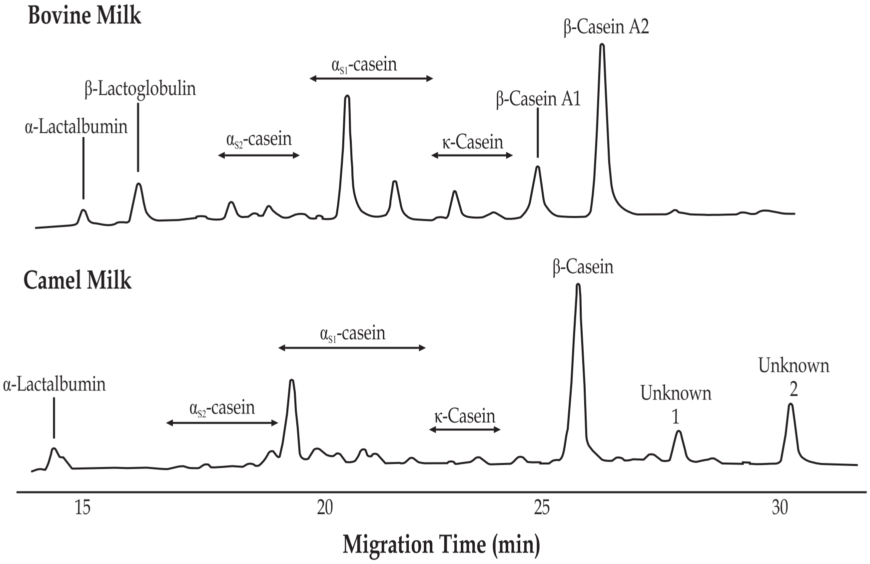

Fig 1. Representative electropherogram of bovine and dromedary camel milk samples determined by capillary electrophoresis according to Mohamed *et al* (2020).

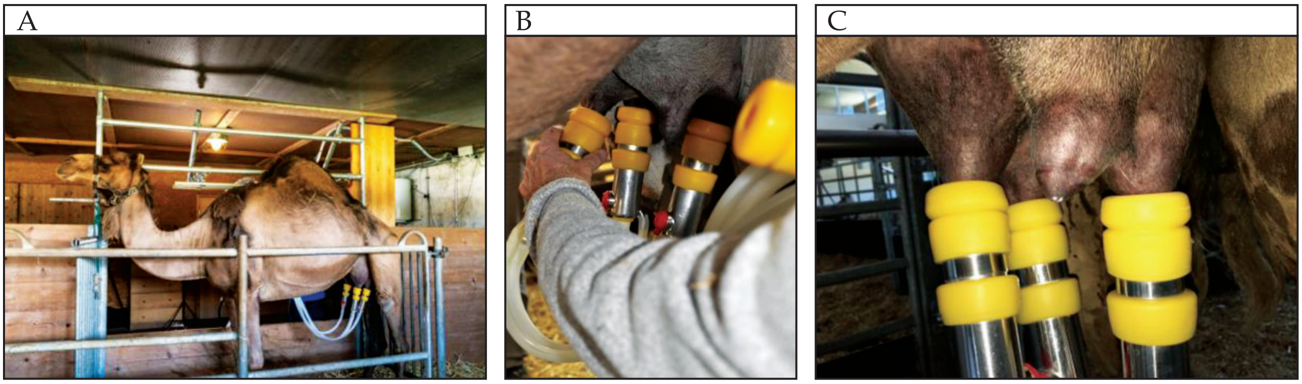

Fig 2. A: A StimuLactor milking machine during milking in camel farm, B+C: Attach milk teat cups.

suitable liquid for these microbiotas (Mohammed *et al,* 2016; Kaskous, 2018a). Therefore, a great deal of research has been done to determine the prevalence of microbial content in the raw camel milk after harvesting from the healthy udder (Wanjohi *et al,* 2013; Matofari *et al,* 2013; Odongo *et al,* 2016; Serda *et al,* 2018; Ismaili *et al,* 2019). Autochthonous microbiota from the exterior of the camel's udder and teats can contribute to the contamination as well as microbiota that are derived from the environment in which the camel is housed and milked (Bachmann,1992; Bekele and Molla, 2001; Hawari and Hassawi, 2008; Omer and Eltinay, 2008; Wanjohi *et al,* 2013; Atigui *et al,* 2023). However, most important it appears to be the contribution of microbiota from teats soiled with manure, mud, and feed. Teats and udders of camels inevitably become contaminated while they are lying or when allowed in dirty lots. The influence of dirty camels on total bacteria counts depends on the extent of soiling of the teat surface and the udder prep procedures employed. Such microbiota could be reduced if hygiene measures were implemented during milking. However, many milkers or camel owners did not adhere to the hygiene measures during milking (Hassen *et al,* 2022). This means that the milk can become contaminated after it leaves the streak canal. Therefore, due to the traditional nature of camel milk production and the lack of appropriate hygiene measures, there is a high risk of milk contamination with microbiota in the milk production sector in many developing countries (Getachew, 2003). The factors that increase microbiota contamination are mainly due to the high ambient temperatures coupled with a lack of on-farm refrigeration, long distances to markets and a lack of transportation options (Husein *et al,* 2016). Matofari *et al* (2013) reported that camel milk is less contaminated at farm because it has not undergone many handlers. The only contamination at this stage may come from the infected udder mostly caused by the cocci group. Abera *et al* (2016) reported that the two dominant factors of the quality of camel raw milk after harvesting are the condition of keeping the product and the time before delivery to the consumer. In any case, a high number of microbiotas in the collected milk samples is an indication of unhygienic milk production conditions (Abdurahman, 2006; Kamal *et al*, 2010). It is noteworthy that many farmers store their raw camel milk in plastic canisters after harvest (Hassen *et al,* 2022). An interesting aspect was that 66% of raw camel milk samples at the farm (Production area) had a microbial load less than 10^5 cfu/ml, compared to 54% at the collection point (bulk tank) and marketing where the microbial load was above 10^6 cfu/ml (Matofari *et al,* 2013). In addition, bicycles, donkeys, and existing vehicles were used to transport raw camel milk from production areas in Kenya to collection or market centres 10 to 20 km away. The ambient temperature in the production areas and on the transport, route was around 39 °C. The raw camel milk reaches the collection points in 2 to 3 hours and the large markets in the cities in 6 to 8 hours (Matofari *et al,* 2013). Through these transportation processes, the raw camel milk could maintain millions of microbiotas, and when this raw camel milk is consumed, the health situation will be severely affected. In this context, Husein *et al* (2016) reported that consuming raw camel milk from production areas was less dangerous than consuming raw camel milk from the market. Furthermore, Abera *et al* (2016) found that about 85.7% of raw camel milk samples in Somali Regional State of Ethiopia were bacterially contaminated and the total bacterial count (TBC) of the contaminated raw camel milk samples was on average 4.75±0.17 log cfu/ml. These bacteria multiply rapidly from the udder to the market. These results indicate that there was a lack of hygiene in the production and milking areas, during transport, and during sale of raw camel milk. A new study in Nigeria has shown that milk samples were taken from five healthy dromedaries and the microbiota *Escherichia coli, Salmonella* in the first camel and *Staphylococcus aureus* in the remaining camels were found (Dogondaji *et al,* 2023). The authors emphasise that the consumption of raw camel milk should therefore, be done with caution. Kaskous (2019) found that by adhering to hygienic measures, good, safe raw camel milk with normal composition was obtained. Therefore, hygiene measures must also be observed after the harvest in order to maintain the quality standard of raw camel milk.

Conclusion

- Regarding the importance of camel milk and the associated related health benefits of its bioactive ingredients, improvements in milking hygiene, milk storage and transport conditions are required to ensure the quality of camel milk meets consumer needs.
- Camels must be kept healthy and raw milk must be refrigerated immediately after milking and during storage and transport.
- The used milking system should adapt to the morphological, anatomical, and physiological characteristics of the udder and teat of the lactating camels and it should achieve a physiologically ideal milking process that meets high animal welfare standards and increases milk production with a high-quality standard.
- To obtain safe camel milk for human consumption, it is recommended to consume pasteurised camel milk.

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