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Growth Inhibition of Foodborne Pathogens in Camel Milk: *Staphylococcus aureus, Listeria monocytogenes, Salmonella* spp. and *E. coli* O157:H7

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Abstract

Abusheliabi A., Al-Holy M.A., Al-Rumaithi H., Al-Khaldi S., Al-Nabulsi A.A., Holley R.A., Ayyash M. (2017): Growth inhibition of foodborne pathogens in camel milk: *Staphylococcus aureus*, *Listeria monocytogenes*, *Salmonella* spp. and *E. coli* O157:H7. Czech J. Food Sci., 35: 311–320.

The growth behaviour of foodborne pathogens (*Staphylococcus aureus, Listeria monocytogenes*, *E. coli* O157:H7 and *Salmonella* spp.) was investigated in pasteurised camel milk and compared with pasteurised bovine milk at different incubation temperatures. This study also aimed to compare the growth patterns of these four foodborne pathogens in pasteurised and raw camel milk. Pasteurised or raw camel milk and pasteurised bovine milk were separately inoculated with a cocktail of three strains of each foodborne pathogen. The inoculated milk samples were incubated at 10, 25, and 37°C. The total bacterial count (TBC) in raw milk and the total thermoduric bacteria count (TDB) in pasteurised milk samples were monitored. Greater growth inhibition rates of four pathogens were obtained for the pasteurised camel milk compared to the pasteurised bovine milk. Raw and pasteurised camel milk exerted bacteriostatic effect against all tested pathogens, particularly for the first 8 h of incubation in milk at the different temperatures. Pasteurised camel milk exerted an inhibitory activity that was equivalent to that of raw camel milk.

Keywords: antimicrobial activity; pasteurisation; bovine milk; growth behaviour

Foodborne diseases are a critical problem all around the world. According to the World Health Organization (WHO), in 2015, 31 foodborne hazards were responsible for 600 million foodborne illnesses and 420 000 deaths globally (WHO 2015). WHO (2015) has also reported that foodborne pathogens (including *Listeria monocytogenes*, enteropathogenic *E. coli*, *Staphylococcus aureus*, and *Salmonella* spp.) account for 65 and 72% of cases of foodborne illnesses and foodborne deaths, respectively. Milk and milk products are considered to be among the primary sources for these pathogens (Oliver *et al.* 2005). As dairy products, camel milk and its products have not received sufficient attention from researchers and food control authorities.

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Camels are found in Africa and Asia and are kept mostly by nomads and tribes living in desert regions. Australia has half a million wild camels, mainly in the Northern Territory. Globally, there are two popular species of camels: one-humped Arabian camels or dromedaries (*Camelus dromedarius*), the camels of the plains; and two-humped Bactrian camels (*Camelus bactrianus*), the camels of the mountains (Fukuda 2013). Camels are raised for milk, meat, fibre (wool and hair), transport and other work; their dung is used as fuel (El-Agamy 2008). Milk is often the most important camel product and is the staple food of nomads. An FAO workshop estimated global camel milk production to be approximately more than 5.3 million litres (Yagill 1982). The Food and Agriculture Organization (Yagill 1982) reported that the countries with the highest annual production of camel milk were Somalia, Saudi Arabia and the United Arab Emirates (UAE). In the UAE, several products from camel milk, including pasteurised camel milk, ice-cream, cheese, camel milk powder, latte coffee and camel milk soap have been developed and are sold in local markets.

Several studies have reported the nutritional benefits of camel milk, which include antihypertensive, hypoglycaemic, hypoallergenic and hypocholesterolaemic effects (Barlowska *et al.* 2011; Al-Juboori *et al.* 2013; Mostafa *et al.* 2013; Sayed *et al.* 2013; Ibrahim & Khalifa 2015). The impact of camel milk on autism has also been reported (Al-Ayadhi & Elamin 2013; Al-Ayadhi *et al.* 2015). The variety of camel milk products and their significant nutritional value have contributed to increasing camel milk consumption. However, the data in the literature related to the safety of camel milk and its products including the growth of foodborne pathogens are scarce. Alall *et al.,* (2012) isolated 5 *Salmonella* spp., 12 *E. coli* strains, and 2 *Listeria monocytogenes* strains from 185 Egyptian camel milk samples and particularly noted the presence of *Salmonella enteritidis*, *Salmonella typhi, Salmonella typhimurium*, *Salmonella anatum*, *E. coli* O157:H7, and *E. coli* O26:H11. Hadush *et al.* (2008) reported the frequencies of *Escherichia coli* and *Staphylococcus aureus* pathogens to be 25 and 7.14%, respectively. The bacteriological quality of 108 camel milk samples was assessed by Abera *et al.* (2016). The authors found that the frequencies of *Staphylococcus* spp., *E. coli*, *Salmonella* spp., and *Enterobacter* spp. were 89.8, 31.5, 17.6, and 5.6%, respectively. These studies prove that camel milk can be contaminated by *Staphylococcus aureus, Listeria monocytogenes*, *Salmonella* spp., and *E. coli* O157:H7 and emphasise the importance of the current study.

Elagamy *et al.* (1992, 1996) reported that camel milk possesses greater quantities of inhibitory constituents compared to bovine milk. These inhibitory properties have been tested against spoilage microorganisms (Lore *et al.* 2005; Conesa *et al.* 2008; Nagy *et al.* 2013; Verraes *et al.* 2014) but not against foodborne pathogens. Recently, Abusheliabi *et al.* (2017) investigated the inhibitory effect of camel milk against *Cronobacter sakazakii*. Controlling foodborne pathogens in camel milk and its products is based on an understanding of pathogen behaviour in camel milk. Therefore, and due to the limited data pertaining to the growth behaviour of foodborne pathogens in camel milk, this study was aimed at investigating the growth patterns of *S. aureus, L. monocytogenes*, *E. coli* O157:H7, and *Salmonella* spp. in pasteurised camel milk in comparison with pasteurised bovine milk at different incubation temperatures and different time intervals, in order to explore if camel milk has any inhibitory effect on these foodborne pathogens. This study also aimed to compare the growth patterns of these four pathogens in pasteurised and raw camel milk to investigate the impact of pasteurisation on the inhibitory properties of camel milk.

MATERIAL AND METHODS

Chemical composition and pH measurements. The chemical composition of raw and pasteurised camel milk and pasteurised bovine milk was determined according to Official methods of analysis of AOAC International (1995). Moisture content was determined using the oven-drying method at 102°C, fat using the Babcock method, protein using the Kjeldahl method and ash using the muffle furnace method. The pH of experimental milk samples was measured during a 24 h period after incubation at 37°C. Measurements were taken at 0, 2, 4, 6, 8, and 24 h using a calibrated digital pH meter (Starter-3100; Ohaus, USA).

Bacterial strains and culture media. The investigated foodborne pathogens were three strains of *S. aureus* (ATCC 15923, DSM 20714, and DSM 18589), three strains of *L. monocytogenes* (ATCC 7644, DSM 20600, and DSM 190094), three species of *Salmonella* (*S. Typhimurium* 02-8423, *S. Kentucky* 06-4701 and *S. Enteritidis* CRIFS 1016) and three strains of *E. coli* O157:H7 (161-84, 1934, and DSM 13526).

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Two *S. aureus* strains (DSM 20714 and DSM 18589), two *L. monocytogenes* strains (DSM 20600 and DSM 190094), and *E. coli* O157:H7 (DSM 13526) were purchased from the Leibniz Institute DSMZ-German Collection of Microorganisms and Cell Cultures (Germany). The rest of the strains were obtained from Prof Richard Holley, Department of Food Science, University of Manitoba (Canada). All strains were kept individually at –80°C in brain heart infusion (BHI) (Oxoid Ltd, UK) broth containing 50% glycerol. Three subculture transfers were performed to resuscitate each culture in BHI broth at 37°C for 24 h in order to reach the stationary phase prior to inoculation into the milk. Then, for each pathogen, 1 ml of each culture was pooled in a 10-ml test tube and mixed to obtain an approximately equal number of cells of each strain in the mixed culture of *S. aureus, L. monocytogenes*, *E. coli* O157:H7 or *Salmonella* spp.

Experiment design. Full-fat pasteurised bovine samples were purchased from a local market in Al-Ain, UAE. Raw camel milk was obtained from a local camel farm in Al-Ain. Raw camel milk was split into two portions; one portion was pasteurised at 72°C for 15 s (similar to bovine milk), and the other portion was used as raw camel milk. This resulted in three types of experimental milk sample: pasteurised bovine, pasteurised camel, and raw camel milk. Experimental milk (9.9 ml) was aseptically transferred into a sterilised empty tube. An aliquot (100 µl) of pathogen cocktail was aseptically pipetted into the experimental milk. The original pathogen cocktail was diluted using 0.1% sterilised peptone water before final inoculation into milk samples to obtain ~ 4 $\log_{10}$ CFU/ml as an initial number in the milk. Inoculated milk samples were incubated at 10, 25 or 37°C and sampled after 2, 4, 8, and 24 h of incubation time. The 10°C temperature represented temperature abuse in market fridges, 25°C represented room temperature for milk consumption and 37°C is the optimum growth temperature for pathogens. For each pathogen, experimental treatments (3 milk types × 3 incubation temperatures × 1 pathogen) were carried out on the same day in triplicates.

Bacterial enumeration. *Salmonella* spp. numbers were determined by surface plating of 100 µl in duplicate onto the surface of bismuth sulphite agar (BSA; Oxoid). After aerobic incubation at 37°C for 24–48 h, typical colonies of *Salmonella* were enumerated. *S. aureus* numbers were enumerated by surface plating of 100 µl in duplicate onto the surface of Baird-Parker agar (Oxoid) supplemented with egg yolk tellurite emulsion (Oxoid). Media were prepared per manufacturer's instructions. After aerobic incubation at 37°C for 48 h, typical black colonies were enumerated. *E. coli* O157:H7 numbers were determined by surface plating 100 µl in duplicate onto the surface of MacConkey sorbitol agar (Oxoid). After aerobic incubation at 37°C for 24 h, typical colourless colonies of *E. coli* O157:H7 were enumerated. *L. monocytogenes* numbers were enumerated by surface plating 100 µl in duplicate onto the surface of *Listeria*-selective PALCAM (Oxoid) medium base containing antimicrobial supplement. After aerobic incubation at 37°C for 24 h, typical black colonies were enumerated. Total bacterial count (TBC) for raw camel milk was enumerated according to ISO 4833 – Microbiology of food and animal feeding stuffs-horizontal method for the enumeration of microorganisms-colony count technique at 30°C (2003) and thermoduric bacteria (TDB) in pasteurised camel milk according to Walkling-Ribeiro *et al.* (2011).

Statistical analysis. For each incubation temperature and sampling time, the independent *t*-test was performed to examine the significance of differences between means of pathogen growth in pasteurised bovine and pasteurised camel milk samples ($P < 0.05$). Similarly, the independent *t*-test was employed to examine the significance of differences between pathogen growth in pasteurised camel milk and raw camel milk samples at each incubation temperature and sampling time. For pH values at 37°C, the independent *t*-test was carried out to compare pH values of pasteurised bovine and pasteurised camel milk and between pH values of pasteurised camel milk and raw camel milk. One-way ANOVA was performed to investigate the effect of sampling time on pH values and pathogen growth in each experimental milk. Tukey's test was employed to compare means between pH values and pathogen growth during the course of sampling in each experimental milk. All statistical analyses were carried out using SPSS v23.0 (IBM Corp., USA).

RESULTS

Milk description. The approximate composition of camel and bovine milk samples is shown in Table 1. The two types of milk have almost the same moisture and lactose contents. However, camel milk has relatively higher ($P < 0.05$) fat but less ($P < 0.05$) protein content, compared to bovine milk.

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Table 1. Gross composition of raw and pasteurised camel milk and bovine milk[1]

Milk	Moisture (%)	Protein (%)	Fat (%)	Ash (%)
Raw camel	88.7 ± 0.11^{a1}	2.8 ± 0.22^{b}	3.7 ± 0.24^{a}	0.78 ± 0.001^{b}
Pasteurised camel	88.1 ± 0.09^{a}	2.6 ± 0.31^{b}	3.5 ± 0.36^{a}	0.78 ± 0.001^{b}
Pasteurised bovine	87.1 ± 0.01^{b}	3.3 ± 0.11^{a}	3.4 ± 0.43^{a}	0.81 ± 0.003^{a}

[1]values are means of at least three replicates ± standard error; [a,b]means within the same column with different superscripts differ significantly ($P < 0.05$)

The changes in pH values of inoculated raw and pasteurised camel milk and pasteurised bovine milk after incubation at 37°C for 24 h are presented in Table 2. A gradual drop in the pH values of raw and pasteurised camel milk was noted over time after inoculation with four pathogens. For experimental milk samples inoculated with *S. aureus*, the reduction in pH ranged between 6.5–4.8, 6.2–5.1, and 6.1–5.0 in pasteurised bovine, pasteurised and raw camel milk after 24 h of incubation, respectively. For milk inoculated with *L. monocytogenes*, pH dropped from 6.5 to 4.9, 6.2 to 5.2, and 6.2 to 5.0 in pasteurised bovine, pasteurised and raw camel milk, respectively. The pH drop in milk inoculated with *Salmonella* spp. ranged between 6.4–4.8, 6.2–5.1, and 6.3–5.0 in pasteurised bovine, pasteurised and raw camel milk, respectively. The pH reductions were 6.2–4.7, 6.2–4.9, and 6.1–5.0 in pasteurised bovine, pasteurised and

Table 2. pH values of raw and pasteurised camel milk and pasteurised bovine milk incubated at 37°C for 24 hours

Pathogen	Incubation time (h)	Pasteurised bovine	Pasteurised camel	Raw camel
Staph. aureus	0	6.5 ± 0.06^{a1}	6.2 ± 0.12^{a}	6.1 ± 0.06^{a}
	2	6.1 ± 0.15^{b}	6.2 ± 0.01^{a}	6.1 ± 0.15^{a}
	4	5.7 ± 0.16^{c}	5.9 ± 0.06^{ab}	5.8 ± 0.16^{b}
	6	5.4 ± 0.11^{d}	5.7 ± 0.08^{b}	5.7 ± 0.11^{c}
	8	5.3 ± 0.23^{d}	5.6 ± 0.32^{c}	5.5 ± 0.13^{c}
	24	4.8 ± 0.03^{e}	5.1 ± 0.71^{c}	5.0 ± 0.03^{d}
L. monocytogenes	0	6.5 ± 0.12^{a}	6.2 ± 0.06^{a}	6.2 ± 0.06^{a}
	2	6.2 ± 0.53^{b}	6.1 ± 0.25^{a}	6.1 ± 0.21^{ab}
	4	5.7 ± 0.17^{c}	5.8 ± 0.13^{b}	5.7 ± 0.13^{b}
	6	5.5 ± 0.08^{cd}	5.6 ± 0.16^{cb}	5.6 ± 0.16^{b}
	8	5.2 ± 0.06^{d}	5.6 ± 0.11^{cb}	5.5 ± 0.12^{cb}
	24	4.9 ± 0.04^{e}	5.2 ± 0.03^{c}	5.0 ± 0.03^{c}
Salmonella spp.	0	6.4 ± 0.12^{a}	6.2 ± 0.06^{a}	6.3 ± 0.06^{a}
	2	6.3 ± 0.02^{a}	6.2 ± 0.11^{a}	6.2 ± 0.11^{a}
	4	6.0 ± 0.05^{b}	5.8 ± 0.11^{b}	5.7 ± 0.11^{b}
	6	5.8 ± 0.07^{c}	5.7 ± 0.13^{b}	5.6 ± 0.13^{b}
	8	5.5 ± 0.29^{c}	5.7 ± 0.10^{bc}	5.6 ± 0.10^{b}
	24	4.8 ± 0.01^{d}	5.1 ± 0.06^{c}	5.0 ± 0.06^{c}
E. coli O157:H7	0	6.2 ± 0.06^{a}	6.2 ± 0.12^{a}	6.1 ± 0.06^{a}
	2	6.0 ± 0.11^{ab}	6.2 ± 0.01^{a}	5.9 ± 0.11^{ab}
	4	5.6 ± 0.11^{b}	5.9 ± 0.08^{b}	5.7 ± 0.11^{b}
	6	5.4 ± 0.09^{c}	5.6 ± 0.06^{c}	5.6 ± 0.09^{c}
	8	5.3 ± 0.11^{c}	5.4 ± 0.23^{c}	5.4 ± 0.11^{c}
	24	4.7 ± 0.01^{d}	4.9 ± 0.01^{d}	5.0 ± 0.01^{d}

[1]values are mean ± standard error of three readings; [a–d]means with different superscripts within a column differ significantly for each pathogen ($P < 0.05$)

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raw camel milk, respectively, when inoculated with *E. coli* O157:H7. Table 2 reveals that the pH reductions in all experimental milks inoculated with *E. coli* O157:H7 were higher compared with other pathogens except in raw camel milk.

The TBC in raw camel milk is shown in Figure 1A, and the TDB count in pasteurised camel milk in Figure 1B. The TBC in raw camel milk did not show a significant increase after 24 h of incubation at 10°C. The TBC counts increased only slowly in the first 8 h of incubation of the raw camel milk at 25°C. However, a significant increase in the TBC was noted after that, with the numbers exceeding 8 $\log_{10}$ CFU/ml. In comparison, at 37°C, the TBC reached to > 8.0 $\log_{10}$ CFU/ml at 37°C. For the TDB, the count remained constant for the whole 24-h incubation period at 10°C, and an increase ($P > 0.05$) of only < 1.0 $\log_{10}$ CFU/ml occurred after 24 h of incubation at 25°C. At 37°C, the TDB started to increase considerably after 4 h of incubation, exceeding 6.0 $\log_{10}$ CFU/ml at the end of the incubation period.

Staphylococcus aureus behaviour. The growth pattern of *Staph. aureus* in raw camel milk and in pasteurised camel and bovine milk at three different growth temperatures (10, 25, and 37°C) is shown in Figures 2A–C. *S. aureus* counts decreased ($P < 0.05$) at 10°C after 2 h of incubation (Figure 2A). However, slow growth ($P > 0.05$) was noted thereafter, and the count remained constant at around 4 $\log_{10}$ after 24 h of inoculation regardless of the milk type. In comparison, at 25°C, the counts in camel milk (raw and pasteurised) remained constant for almost 8 h after inoculation and an increase in *S. aureus* numbers were observed thereafter (6 $\log_{10}$ after 24 h). In comparison, in the bovine milk samples at the same temperature, an increase in the number was observed after 4 h of incubation, and numbers had surpassed 7 $\log_{10}$ after 24 h of inoculation.

At 37°C (Figure 2C), an instant growth of *Staph. aureus* in pasteurised bovine milk was noted, and the

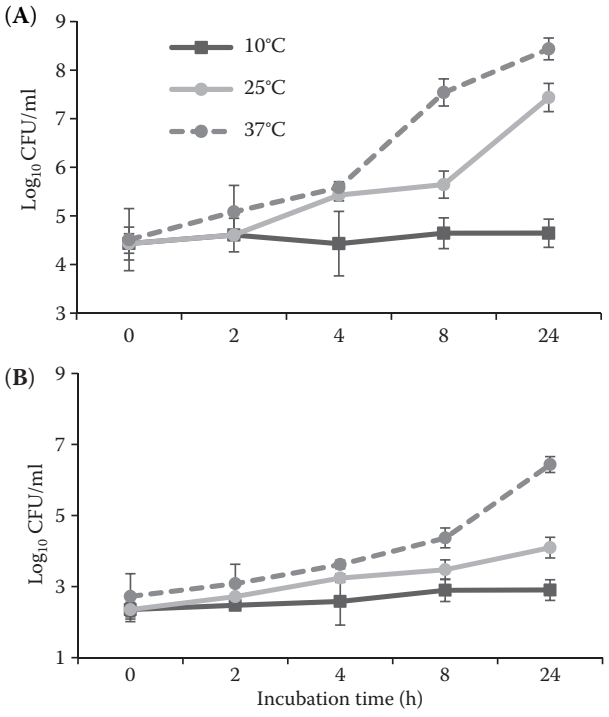

Figure 1. Total bacterial count (TBC) of raw camel milk (**A**) and thermoduric bacterial count (TDC) of pasteurised camel milk (**B**)

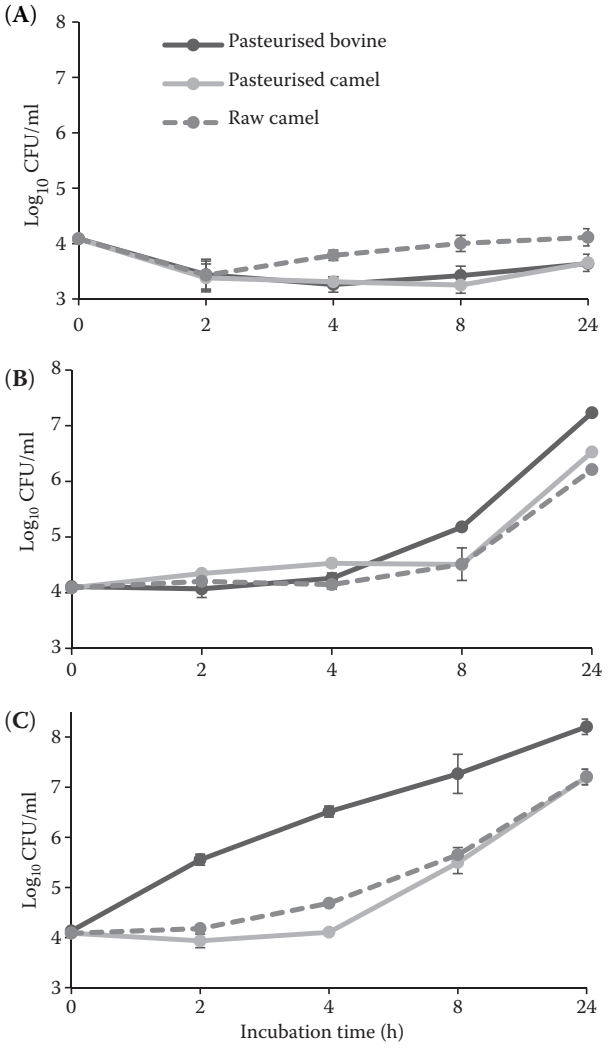

Figure 2. Counts of *Staph. aureus* cocktail inoculated into raw camel milk, pasteurised camel milk, and pasteurised bovine milk at different incubation temperatures: 10°C (**A**), 25°C (**B**), and 37°C (**C**)

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numbers exceeded 8 $\log_{10}$ after 24 h of inoculation. The numbers of *S. aureus* remained relatively stable for almost 4 h in raw and pasteurised camel milk compared to pasteurised bovine milk, but a gradual increase in the numbers was observed after that. Nonetheless, the bacterial count was approximately 1 $\log_{10}$ CFU/ml lower compared to the count noted in pasteurised bovine milk after 24 h of inoculation, indicating some inhibitory effect of camel milk. In another study, it was reported that colostrum and regular camel milk exerted bacteriostatic effects against *L. monocytogenes* stored for almost 8 h either at 4°C or 20°C. After that, the growth rate tended to increase (Benkerroum *et al.* 2004). These earlier results are in agreement with the growth pattern of *S. aureus* observed in the current study, where a bacteriostatic effect was observed for the first 8 h at 25°C, with a re-growth of the organism taking place thereafter.

Listeria monocytogenes behaviour. The growth patterns of *L. monocytogenes* in raw and pasteurised camel milk and pasteurised bovine milk incubated at 10, 25, and 37°C for 24 h are shown in Figures 3A–C, respectively. At 10°C, *L. monocytogenes* growth did not differ significantly among the different milks during incubation (Figure 3A). Figure 3B shows that at 25°C, *L. monocytogenes* increased significantly ($P < 0.05$) during incubation in all types of milk. After 2 h of incubation, *L. monocytogenes* growth was higher ($P < 0.05$) in pasteurised bovine milk than in raw or pasteurised camel milk. This difference in *L. monocytogenes* growth in bovine and camel milk became more obvious after 8 and 24 h of incubation (Figure 3B). At 37°C, *L. monocytogenes* growth increased significantly ($P < 0.05$) in all milk samples during incubation. Similar to the picture at 25°C, growth of *L. monocytogenes* at 37°C for 24 h resulted in higher values ($P < 0.05$) in bovine milk compared to both camel milk types (Figure 3C). The growth of *L. monocytogenes* was lower by approximately 1 $\log_{10}$ CFU/ml from 4 h of incubation onwards (Figure 3C).

Salmonella spp. behaviour. The growth pattern of a cocktail of three *Salmonella* spp. in raw camel milk, pasteurised camel and pasteurised bovine milk at three different growth temperatures (10, 25, and 37°C) is shown in Figures 4A–C. No increase in the numbers of *Salmonella* spp. was noted throughout the 24 h incubation period at 10°C. In fact, the bacterial count decreased slightly compared to the initial inoculation level at the end of the incubation period. In comparison, at 25°C, the *Salmonella*

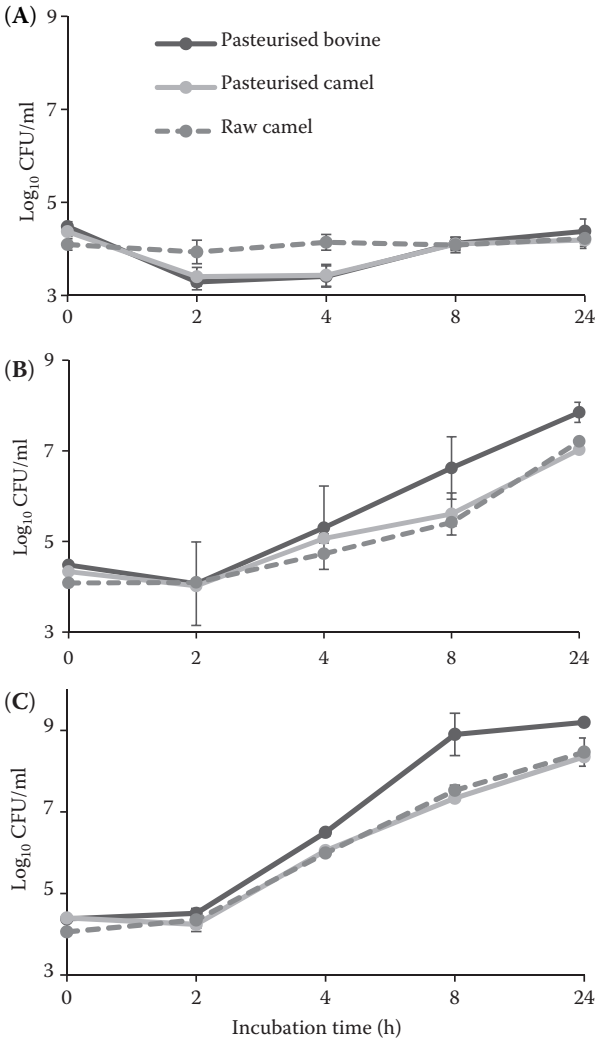

Figure 3. Counts of *L. monocytogenes* cocktail inoculated into raw camel milk, pasteurised camel milk, and pasteurised bovine milk at different incubation temperatures: 10°C (**A**), 25°C (**B**), and 37°C (**C**)

count remained stable for 2 h, and a sharp increase in counts was observed subsequently. Nonetheless, *Salmonella* spp. counts at 25°C were lower ($P < 0.05$) in inoculated raw camel (< 7.0 $\log_{10}$ after 24 h) compared to pasteurised camel and bovine milk types. Figure 4C shows the growth pattern of *Salmonella* spp. at 37°C. Again, the growth of *Salmonella* was significantly ($P < 0.05$) lower in inoculated raw camel milk, particularly during the first 4 h of incubation. After that, a sharp increase in the numbers was noted, and the numbers in inoculated bovine milk were significantly higher ($P < 0.05$) compared to inoculated raw and pasteurised camel milk.

E. coli O157:H7 behaviour. The growth of *E. coli* O157:H7 in raw and pasteurised camel milk and

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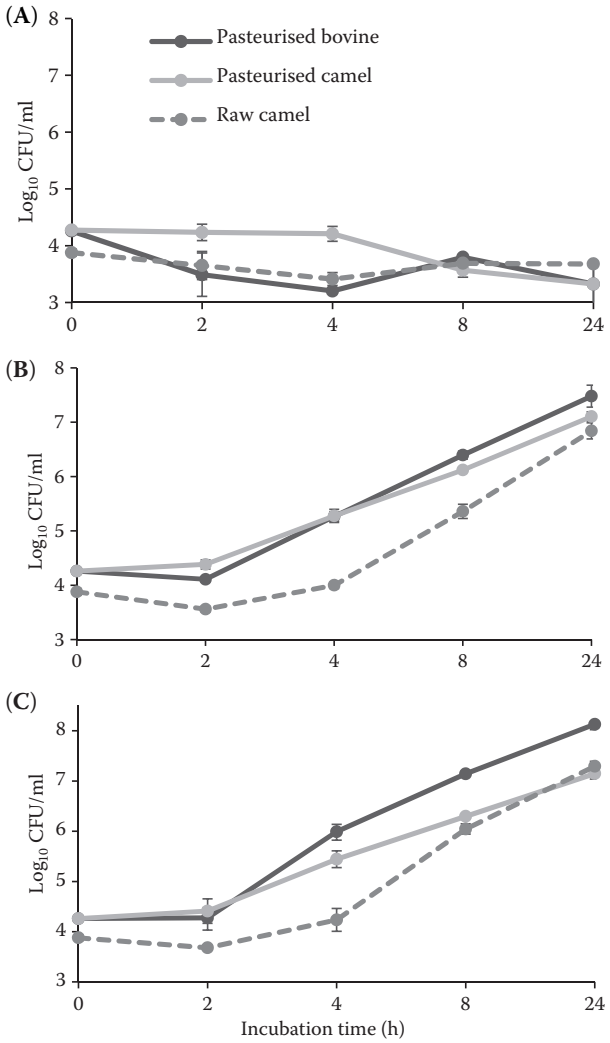

Figure 4. Counts of *Salmonella* spp. inoculated into raw camel milk, pasteurised camel milk, and pasteurised bovine milk at different incubation temperatures: 10°C (**A**), 25°C (**B**), and 37°C (**C**)

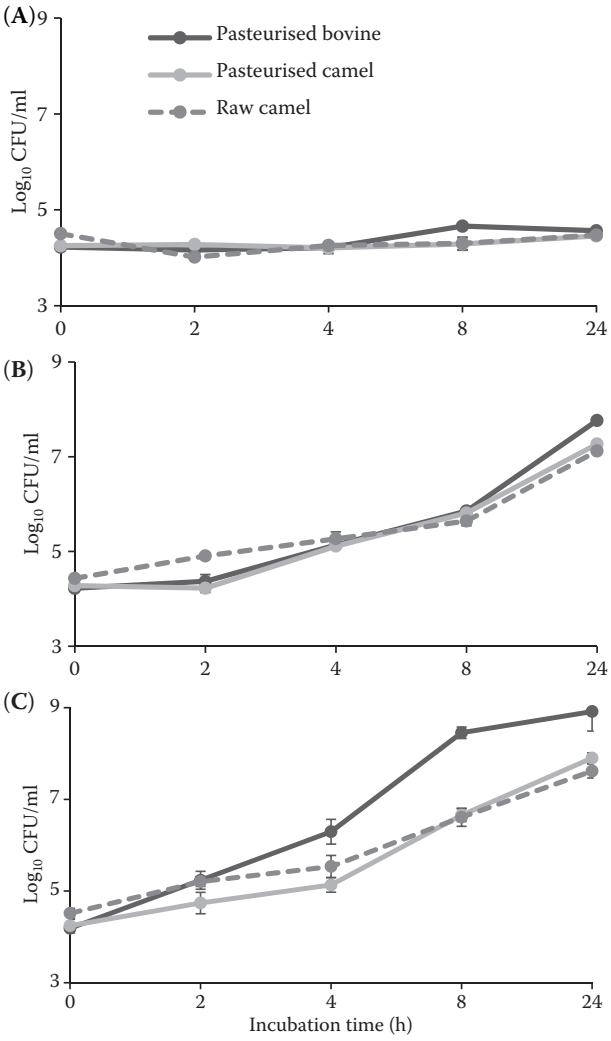

Figure 5. Counts of *E. coli* O157:H7 cocktail inoculated into raw camel milk, pasteurised camel milk and pasteurised bovine milk at different incubation temperatures: 10°C (**A**), 25°C (**B**) and 37°C (**C**)

pasteurised bovine milk incubated at 10, 25 or 37°C for 24 h is presented in Figures 5A–C, respectively. At 10°C, *E. coli* O157:H7 growth remained relatively stable over the course of 24 h of incubation. Growth did not differ ($P > 0.05$) between bovine and camel milk during the same incubation (Figure 5A). At 25°C, *E. coli* O157:H7 growth in all experimental milks increased ($P < 0.05$) with incubation time. After 8 h of incubation, *E. coli* O157:H7 growth in bovine milk was higher ($P < 0.05$) compared with both camel milks (Figure 5B). At 37°C, *E. coli* O157:H7 count differed significantly ($P < 0.05$) between experimental milks, especially after 4 h of incubation. The count in both types of camel milk was lower ($P < 0.05$) compared with bovine milk (Figure 5C).

DISCUSSION

Chemical compositions were determined in this study in order to have a better description of the experimental milk samples. The significant differences in chemical composition (protein, fat, carbohydrate) between camel milk and bovine milk is attributed to differences between in species. The chemical composition reported in this study is in agreement with what has been reported for regular dromedary camel milk (Elamin & Wilcox 1992; Haddadin *et al.* 2008).

Monitoring the changes in pH over incubation time is useful for interpret differences in pathogen growth. The reductions in the pH values of the experimental milk may be attributed to increasing TBC

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in raw camel milk and TDB in pasteurised bovine and camel milk over the course of incubation. TBC and TDB can ferment lactose and produce organic acids, mainly lactic acid (Puniya 2015). Table 2 shows that the drop rate in pH of pasteurised bovine milk was higher compared with pasteurised and raw camel milk. This higher rate may be due to higher amounts of antimicrobials in camel milk (pasteurised and raw) compared with bovine milk (Elagamy *et al.* 1996). The lower pH values in the experimental milk samples inoculated with *E. coli* O157:H7 may be due to the enhanced ability of *E. coli* to ferment lactose and produce lactic acid compared to the other tested pathogens (Hancock *et al.* 1994).

In the current study, we investigated the growth behaviour of two Gram-positive foodborne pathogens, *Staph. aureus* and *L. monocytogenes*, and two Gram-negative pathogens, *E. coli* O157:H7 and *Salmonella* spp., inoculated into pasteurised and raw camel milk and pasteurised bovine milk incubated at different growth temperatures. Incubation temperature and time had, as expected, a significant effect on the growth of all pathogens. In general, the incubation of experimental milk samples at 10°C negated the influence of milk type on pathogen growth. This effect of 10°C incubation temperature may be attributed to the low metabolic activity in the cells of pathogens. The lower growth of *S. aureus, L. monocytogenes, E. coli* O157:H7, and *Salmonella* spp. in pasteurised and raw camel milk compared with bovine milk at 25 and 37°C may be attributed to the fact that camel milk possesses higher numbers of antimicrobial constituents than bovine milk. This has been verified by Salami *et al.* (2010) who reported that camel milk possesses higher antimicrobial activity compared with bovine milk. Elagamy *et al.* (1996) reported that camel milk has higher concentrations of lysozyme, IgG, and lactoferrin than bovine and buffalo milk. Also, these antimicrobial factors have higher heat resistance compared to those present in bovine and buffalo milk (Elagamy 2000). Additionally, the lactoperoxidase present in camel milk inhibits various Gram-positive and Gram-negative bacteria (García-Graells *et al.* 2000).

In this study, pasteurised and unpasteurised camel milk had almost identical inhibitory patterns. It has been found that heating may partially destroy the inhibitory properties of raw milk, such as the lysozyme and the lactoperoxidase systems (Marks *et al.* 2001). Furthermore, data from Figures 2–5 suggest that the inhibitory activity of camel milk (raw or pasteurised) did not last longer than 8 h, and was followed by re-growth of bacterial cells. This phenomenon was also reported by Benkerroum *et al.* (2004), who reported that camel colostrum samples exerted a bacteriostatic effect against *L. monocytogenes* during the first 8 h of incubation at 20°C; however, re-growth was observed thereafter. On the other hand, the lactoperoxidase system exerted inhibitory effects on *E. coli* and *L. innocua* the grown at 20°C for 24 h, but did not cause any inactivation after this period (García-Graells *et al.* 2000).

CONCLUSIONS

In conclusion, the current study indicates that all investigated pathogens in this study grew less well in raw and pasteurised camel milk compared to bovine milk. The inhibitory effect of camel milk against the four foodborne pathogens used in the current study was more bacteriostatic than bactericidal, and generally did not last for more than 8 h at high incubation temperatures (25 and 37°C). The inhibitory activity exerted by camel milk was not affected by milk pasteurisation as both raw and pasteurised camel milk exerted comparable inhibitory patterns. In general, raw and pasteurised camel milk resulted in reductions in the counts of *Staph. aureus* and *Salmonella* spp. by approximately 1 $\log_{10}$, which is greater compared to bovine milk. Further studies may be needed to explore the inhibitory effects of camel milk against other common foodborne pathogens and to find ways to enhance the natural antimicrobial properties present in camel milk.

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