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RESEARCH PAPER

Antioxidant and antibacterial activity of two dairy camel milk products: yoghurt and cheese

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Abstract

This work focused on producing yoghurt and cheese from camel milk and assessing their physicochemical features along with biological activities. Converting camel milk into fermented products such as yoghurt and cheese is a common preservation approach; however, it remains challenging due to the difficulty of achieving proper coagulation. In this study, camel milk cheese was prepared using enzymatic extracts derived from kiwi and artichoke and compared with cheese obtained with commercial chymosin. The analyses revealed that the cheeses differed in their physicochemical profiles: kiwi extract produced a more acidic product with a higher protein concentration (40.25 g/L) than that obtained with artichoke extract (32.43 g/L). Cheese yield was also greater with the plant enzymes (22.66% for kiwi and 21.06% for artichoke) compared with chymosin (15.55%). Camel milk yoghurt displayed notable physicochemical properties, including elevated protein levels (23.44 g/L), high viscosity (300 cP), and considerable lactose, acidity, and ash content. The antioxidant capacity was assessed using DPPH radical scavenging, ferric reducing power, and hydrogen peroxide scavenging assays. Results showed a dose-dependent increase in antioxidant activity, with camel yoghurt and cheese exhibiting maximum values of 61.58% and 14.9%, respectively, when compared with ascorbic acid. Antibacterial potential was determined using the agar diffusion method against seven pathogenic bacteria. Both camel milk yoghurt and cheese demonstrated significant inhibitory effects on all tested strains.

Keywords

Camel milk, Cheese, yogurt, antioxidant activity, antibacterial activity

Introduction

Camel milk presents unique compositional features that make it an attractive substitute for bovine milk. In comparison with milk from other ruminants, it is appreciated for its easy digestibility in the human gut, a property linked to its smaller fat globules and low allergenic potential. Importantly, camel milk does not contain β-lactoglobulin—one of the main allergens present in cow's milk—thus representing a safer alternative for individuals with dairy sensitivities (Lajnaf et al. 2022).

The whey proteins, caseins, and lactic acid bacteria (LAB) present in camel milk have been widely investigated for their health-promoting roles, including antioxidant, probiotic, antimicrobial, anti-inflammatory, and immunomodulatory effects (Alhaj et al. 2022). Moreover, recent findings indicate that fermentation and gastrointestinal digestion of camel milk proteins can generate bioactive peptides with strong radical-scavenging capacity and immune-enhancing functions (Zhang et al. 2023). Camel milk continues to serve as a key dietary component for nomadic communities, where it is consumed in both raw and fermented forms. Although yogurt and cheese production originally aimed to extend the shelf life of milk, the use of diverse microbial starters has since expanded the range of fermented camel milk products, offering varied textures, flavors, and functional health benefits (Rahman et al. 2024).

Camel milk is characterized by its limited coagulation ability, which poses challenges for producing conventional dairy products such as cheese, yoghurt, and butter. The slow progress in developing and standardizing camel milk–based dairy products is largely linked to its distinctive structural and functional properties (Seifu 2023). For instance, the relatively low level of κ-casein weakens the casein micelle structure, causing it to disintegrate during curd cutting, which in turn promotes excessive whey loss and reduces cheese yield (Seifu 2023). Recent advances have demonstrated better results in camel milk yogurt production through the incorporation of stabilizers such as gelatin, alginate, and calcium, which contribute to improved sensory attributes and texture (Ayyash et al. 2023). Similarly, cheesemaking from camel milk has become more practical with the introduction of alternative coagulants, including camel chymosin and enzymes of plant origin (Ait et al. 2023). Plant-based rennets, particularly extracts from kiwi (*Actinidia deliciosa*) and artichoke (*Cynara scolymus*), have been identified as promising substitutes for conventional animal chymosin in cheese manufacture. Kiwifruit contains actinidin, a cysteine protease known for its strong milk-clotting ability and a favorable ratio of milk-clotting to proteolytic activity, similar to that of calf rennet. This enzyme shows peak performance under standard cheesemaking conditions, namely at pH 5.5 and 40 °C (Nicosia et al. 2022). Moreover, cheeses produced using kiwi extract have been reported to possess enriched nutraceutical qualities, with increased polyphenol and phytosterol contents, while maintaining acceptable flavor characteristics (Serra 2020). Likewise, artichoke extracts have shown notable potential as milk-clotting agents, mainly due to their content of aspartic proteases concentrated in mature flower heads. These enzymes act selectively on casein micelles, making them effective candidates for dairy coagulation (Bolivar et al. 2023). Cheeses produced with artichoke-derived coagulants have also been reported to display favorable texture and sensory properties, comparable to those obtained with conventional rennet (Pacifico et al. 2024). By comparison, the use of chymosin, a traditional animal-derived coagulant, often results in cheeses with higher water retention and a more elastic consistency, characteristics that may not always suit certain cheese types.

Ongoing studies remain crucial to improving the technological performance, quality, and yield of dairy products based on camel milk. Advancements in camel milk yogurt and cheese production could not only broaden the range of dairy products available on the market but also provide greater economic opportunities and enhance the livelihoods of camel herding communities.

Material and methods

Sampling

Camel milk was obtained from dromedary camels (Camelus dromedarius) reared in the experimental herd of the Arid Regions Institute (IRA, Medenine, Tunisia). The samples were transported to the laboratory in insulated containers and immediately subjected to analysis and processing.

The enzymatic extracts of kiwi (*Actinidia deliciosa*) and artichoke (*Cynara scolymus*) are already prepared as mentioned in Fguiri et al. 2021 and stored in the laboratory at -20 °C.

Yoghurt manufacture

Fresh raw camel milk was first preheated to 65 °C and then homogenized. Pasteurization was carried out at 65 °C for 30 min, after which the milk was cooled to 42 °C. To reach a dry matter content of 14%, skim milk powder was added. The prepared milk was subsequently inoculated with a starter culture containing *Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*.

Cheese making process

Camel milk was subjected to pasteurization at 65 °C for 30 min and subsequently cooled to 40 °C. After approximately one hour, enzymatic extracts derived from kiwi and artichoke were incorporated at a level of 10% (v/v) and thoroughly mixed. The inoculated milk was then incubated at 37 °C for 24 h. Following coagulation, the whey was removed, and the resulting fresh cheese was stored at 4 °C until further analysis.

Yoghurt and cheese characterization

Physicochemical analyses were carried out following international standard procedures (AFNOR 1993). Total protein content was quantified using the classical Kjeldahl method (1883).

Antioxidant properties

DPPH radical scavenging activity

The ability to scavenge 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals was assessed following the method of Bersuder et al. (1998), with minor modifications. Briefly, yoghurt and cheese extracts (1–7 mg/mL) were mixed with a DPPH ethanolic solution (125 µM) and kept in the dark for 1 h at room temperature. Absorbance was then recorded at 517 nm using a UV-Vis spectrophotometer (Cecil CE 2041; Cecil Instruments Ltd). Results were expressed as scavenging percentage using the formula:

$$\text{DPPH scavenging activity (\%)} = [(Ac - As) / Ac] \times 100$$

where *Ac* is the absorbance of the control and *As* that of the sample.

Ferric reducing antioxidant power (FRAP)

The reducing activity was determined according to Wu et al. (2003), with modifications. Samples (1–20 mg/mL) were reacted with phosphate buffer (0.2 M, pH 6.6) and potassium ferricyanide (1%, w/v), incubated at 50 °C for 20 min, and treated with trichloroacetic acid (10%, w/v). After centrifugation (3000 × g, 10 min), the supernatant was mixed with distilled water and ferric chloride (0.1%, w/v). Absorbance was measured at 700 nm after 10 min.

Hydrogen peroxide scavenging assay

Hydrogen peroxide scavenging activity was evaluated as described in previous studies, using ascorbic acid (1 g/L) as a positive control. Samples (yoghurt, milk, and cheese) were mixed with H_2O_2 solution (40 mM), and absorbance was recorded at 230 nm at the start and after 60 min of incubation.

Antibacterial activity

Antibacterial activity was evaluated using the agar well diffusion method. The test organisms included *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Salmonella typhi*, *Listeria innocua*, *Pseudomonas aeruginosa*, and *Enterococcus faecalis*, all obtained from the laboratory culture collection. Pathogenic strains were first cultured in Brain Heart Infusion (BHI) broth and incubated for 24 h at 37 °C. Antibacterial activity was then assessed according to the procedure of Barefoot et al. (1983), with modifications. Briefly, yoghurt and cheese samples were placed in 4.5 mm wells prepared aseptically in Mueller–Hinton agar previously inoculated with the target strain. Each well was filled with 80 µL of sample, and plates were kept at 4 °C for 4 h to allow proper diffusion of antimicrobial compounds (Doumadji et al. 2010). Incubation was then carried out at 37 °C, and inhibition zones were evaluated after 24–48 h (Hwanhlem et al. 2011).

The diameter of the inhibition zones (Zi, mm) was measured, and inhibition was considered positive when Zi exceeded 2 mm (Thompson et al. 1996).

$$\text{Zi (mm)} = \text{inhibition zone diameter (mm)} - \text{Wells diameter (4.5 mm)}$$

Statistical analysis

All data were analyzed by analysis of variance (ANOVA) using the GLM procedure in SAS software (version 9.0). Results are presented as mean ± standard deviation, and mean comparisons were performed using Duncan's multiple range test at a significance level of $p \leq 0.05$ (Cochran and Cox 1992). Each measurement was conducted in triplicate.

Result and discussion

Physicochemical characteristics of camel yoghurt

The physical characteristics of yoghurt are crucial in determining its overall quality. Table 1 presents the physicochemical properties of camel milk yoghurt. Its acidity largely contributes to the characteristic sour and refreshing taste. In the current study, the average titratable acidity of camel milk yoghurt was 1.18%, which is higher than the 0.78% reported by Bhagiel et al. (2015). Al-Zoreky and Al-Otaibi (2015) recorded a pH range of 4.59–4.63 and titratable acidity of 0.71–0.87% lactic acid for camel milk yoghurt produced in Saudi Arabia. Hashim et al. (2009) reported pH values between 4.3 and 4.5 and titratable acidity ranging from 0.98 to 1.16% for yoghurt prepared with added gelatin, alginates, and calcium chloride. The pH in this study was 4.28, indicating a relatively higher acidity.

Table 1. The physicochemical characteristics of camel yoghurt.

	Camel yoghurt	P-value
pH	4.28 ± 0.02	<0.0001
Acidity (°D)	118.33 ± 10.11	0.54
Viscosity (cP)	300 ± 31.6	<0.0001
Dry Matter (g/l)	124.66 ± 3	0.0002
Ash (g/l)	8.44 ± 1.08	<0.0001
Fat (%)	36.16 ± 4.67	<0.0001
Proteins (%)	23.44 ± 2.26	0.005
Lactose (g/l)	13.59 ± 0.99	0.001

The difference is statistically significant if $p < 0.01$.

The total solids (TS) content measured in the present study was 12.24%, exceeding the values reported by Bhagiel et al. (2015) and Bashir (2009), which were 11.83% and 11.3%, respectively. TS content in yoghurt is influenced by the TS of the raw milk, which varies seasonally; it tends to decrease during hot seasons due to higher water content in camel milk to support calf nourishment (Bhagiel et al. 2015).

The ash content in the yoghurt analyzed here was higher than the 0.71% reported by Eissa et al. (2011) for camel milk yoghurt produced in Sudan. Ash content reflects mineral levels, which are essential for bone and teeth development and various physiological functions (Bibiana and Joseph 2014). The protein content of the yoghurt was 23.44%, while lactose concentration was 13.59 g/L.

Physicochemical characteristics of camel milk cheese

The physicochemical properties of camel milk cheese are summarized in Table 2. Significant differences ($P < 0.05$) were observed among cheese samples prepared using kiwi and artichoke crude extracts (KCE, ACE) and commercial camel chymosin (CC).

In this study, cheese produced from camel milk showed lower pH values compared to those reported in the literature. For example, Fguiri et al. (2021) reported a pH of 6.01 for camel milk cheese prepared with kiwi extract, while Inayat et al. (2003) recorded a similar pH of 5.23 for cheese made with CC, comparable to the values obtained here. The higher titratable acidity observed for KCE- and ACE-coagulated cheese may be attributed to the type of coagulant, the processing temperature, and the duration of cheese-making, all of which can influence the acidification process.

Total solids were higher in cheese prepared with KCE compared to those made with ACE and CC (Table 2). Previous studies have reported higher total solids in camel milk cheese, e.g., 44.4% and 45.5% by Khan et al. (2004) and Mehaia (1993), respectively. Such variations can be influenced by multiple factors, including the composition of ingredients and the ash content of the raw milk. Mehaia (2006), for instance, reported that the addition of salt during cheese production increased the ash content of Domiati cheese.

Protein content and cheese yield were also greater in samples prepared with KCE and ACE than with CC (Table 2). Differences in protein levels among cheese types may result from the hydrolytic activity of the coagulants used (Bekele 2014). In this study, cheese yields were 22.66% with kiwi extract (*Actinidia deliciosa*) and 21.06% with artichoke extract (*Cynara scolymus*), both significantly higher than the yield obtained with commercial chymosin (15.55%). These results indicate that plant-derived proteases can serve as effective alternatives to animal rennet, offering comparable or even superior coagulation efficiency under specific conditions.

Table 2. physicochemical characteristics of camel milk cheese.

	CC	KCE	ACE	P-Value
pH	5.57 ± 0.39	4.44 ± 0.04	4.42 ± 0.01	<0.0001
Acidity (°D)	83.3 ± 5.7	156.56 ± 20.8	193.33 ± 5.7	0.0002
Dry Matter (g/l)	28.5 ± 2.45	31.5 ± 0.38	25.4 ± 1.1	<0.0001
Ash (g/l)	0.29 ± 0.04	0.15 ± 0.01	0.16 ± 0.01	0.0019
Fat (%)	16.5 ± 2.1	9.5 ± 0.5	16.5 ± 0.71	0.001
Proteins (%)	17.67 ± 1.5	40.25 ± 0.005	32.43 ± 1.5	0.0005
Lactose (g/l)	9.6 ± 1.2	10.44 ± 0.8	8.7 ± 0.3	0.01
Yield (%)	15.55	22.66	21.07	0.01

CC: Camel Chymosin; KCE: Kiwi Curde Extract, ACE: Artichoke Curde Extract ; The difference is statistically significant if $p < 0.01$.

Recent research supports these findings, emphasizing the interest in plant-based milk-clotting enzymes for ethical, dietary, and economic reasons. For instance, García-Gómez et al. (2020) demonstrated that actinidin in kiwi extract is a cysteine protease capable of efficient milk coagulation while imparting unique sensory properties to the cheese. Similarly, Feiden et al. (2023) showed that artichoke flower extracts, rich in aspartic proteases such as cynarase, provide high clotting activity and yield without adversely affecting texture.

However, it is important to consider that the use of plant-based coagulants can influence flavor, texture, and ripening profiles differently compared to animal rennet, which warrants further standardization and optimization in industrial cheese-making applications (Kilic and Koyuncu 2024).

Antioxidant activity of camel yoghurt

In this study, the antioxidant properties of camel milk yoghurt were assessed using DPPH radical scavenging, ferric reducing antioxidant power (FRAP), and hydrogen peroxide (H_2O_2) scavenging assays.

Phenolic compounds are considered the primary contributors to antioxidant activity (Sroska and Cisowski 2003). In addition, the proteolysis of milk proteins (Lourens-Hattingh and Viljoen 2001) and the production of organic acids (Correia et al. 2005), resulting from microbial metabolism during fermentation and refrigerated storage, may also contribute to the observed antioxidant effects.

Fig. 1 A reports the DPPH radical-scavenging capacity of camel yoghurt in comparison with ascorbic acid. Camel yoghurt possessed great DPPH scavenging capacity (86.57%), this result is in agreement with those of Virtanen et al. (2007) who reported that antioxidant activity increased during fermentation in some cases. Several studies have shown that fermented camel milk can release peptides having various biological activities. The release of peptides with antioxidant activity during fermentation of camel milk has been demonstrated by several researchers. (Moslehishad et al. (2013); Balakrishnan and Agrawal (2014); Soleymanzadeh et al. (2016); Ayyash et al. (2018)).

Fig. 1B shows the results of H_2O_2 trapping test of camel yoghurt in comparison with ascorbic acid. Camel yoghurt possessed high antioxidant activity (33.87%).

Fig. 1C shows the ferric reducing antioxidant power (FRAP) of camel milk yoghurt at different concentrations. The FRAP values of all samples increased with concentration, indicating a dose-dependent effect. At 2.5 mg/mL, camel milk yoghurt exhibited higher antioxidant activity than the standard. These findings are consistent with those of Ayyash et al. (2017), who reported that fermented camel milk demonstrated greater antioxidant activity compared to bovine milk.

Antioxidant activity of camel cheese

Fig. 2 shows antioxidant activity of camel milk cheese manufactured with kiwi and artichoke extract compared with chymosin and standard (acid ascorbic).

Camel milk cheese with artichoke extract showed higher antioxidant activity than that with kiwi and chymosin based on FRAP, H_2O_2 trapping test and DPPH assays.

Fig. 2 showed significantly that the DPPH radical scavenging activity of camel cheese with artichoke was very high (75.82%) and close to ascorbic acid activity 88.15%. The antioxidant activity of camel cheese with kiwi was

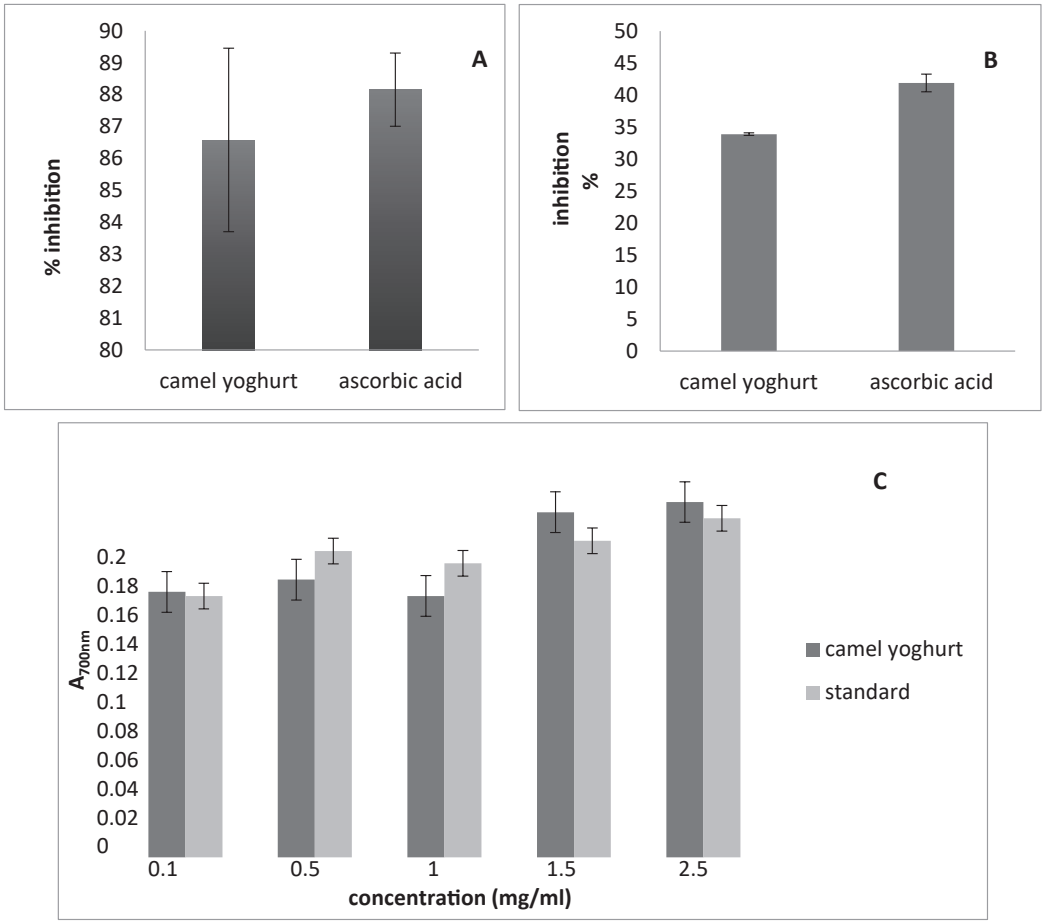

Figure 1. Antioxidant activities of camel yoghurt: **A.** DPPH radical-scavenging activity; **B.** H_2O_2 trapping test; **C.** FRAP ferric reducing power assay.

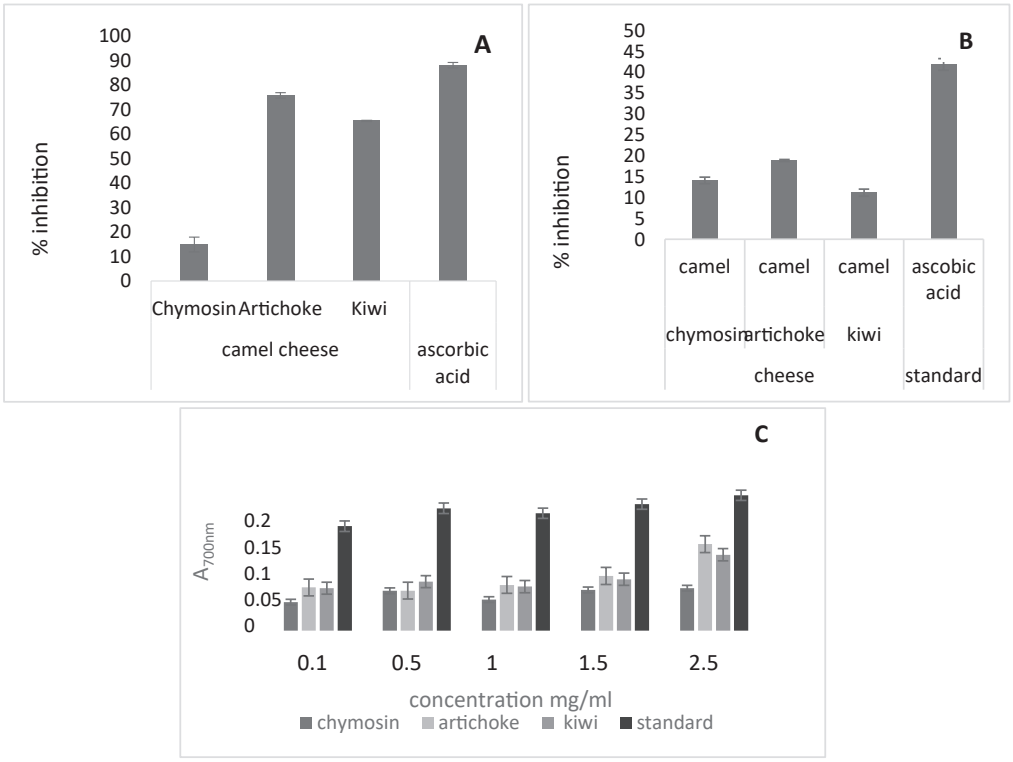

Figure 2. Antioxidant activities of camel Cheese: **A.** DPPH radical-scavenging activity; **B.** H_2O_2 trapping test; **C.** FRAP ferric reducing power assay.

65.4%. This may be due to camel milk proteins which have the ability to neutralize DPPH radicals (Brandelli et al. 2015; Saadi et al. 2015).The antioxidant activity of camel milk can also be attributed to its high ascorbic acid content (Stahl et al. 2006). Moreover Gil-Izquierdo (2001) and Fratianni (2007) reported that artichoke leaves are used in traditional medicine for their healing virtues and their antioxidant and antimicrobial properties. These biological activities are essentially attributed to caffeoylquinic acids and their derivatives (chlorogenic acid and cynarin) and to flavonoids (luteolin 7-O-glucoside).

Antibacterial activity of camel yoghurt

The antibacterial activity of camel milk yoghurt samples is shown in Fig. 3. All tested samples exhibited notable inhibitory effects against the pathogenic strains, with the strongest activity observed against *Enterococcus faecalis* (23 mm) and the weakest against *Pseudomonas aeruginosa* (8 mm).

Previous studies have investigated the effects of various fermented products, including yoghurt and kefir, on a broad spectrum of Gram-positive and Gram-negative bacteria. These investigations demonstrated that microorganisms present in fermented foods can inhibit the growth of *Staphylococcus aureus*, *Shigella* spp., *Salmonella* spp., *Escherichia coli*, *Listeria monocytogenes*, *Bacillus cereus*, *Bacillus subtilis*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, and *Enterococcus faecalis* (Namaei et al. 2015; Kim et al. 2016). The antimicrobial effects are likely due to bioactive compounds such as organic acids, ethanol, hydrogen peroxide, diacetyl, peptides, and possibly bacteriocins, among other inhibitory substances.

Antibacterial activity of camel cheese

Fig. 4 shows the antibacterial activity of camel milk cheese against some pathogenic bacteria.

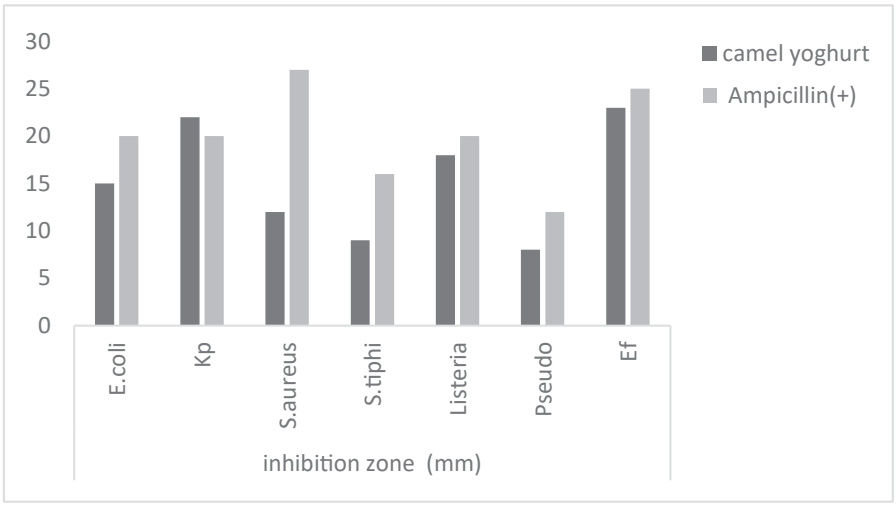

Figure 3. Antibacterial activity of camel yoghurt against 7 pathogenic strains (*E. coli*; *Klebsiella pneumonia*: Kp; *S. aureus*; *Salmonella tiphi*; *Listeria inocua*; *Pseudomonas aeruginosa*; *Enterococcus feacalis*).

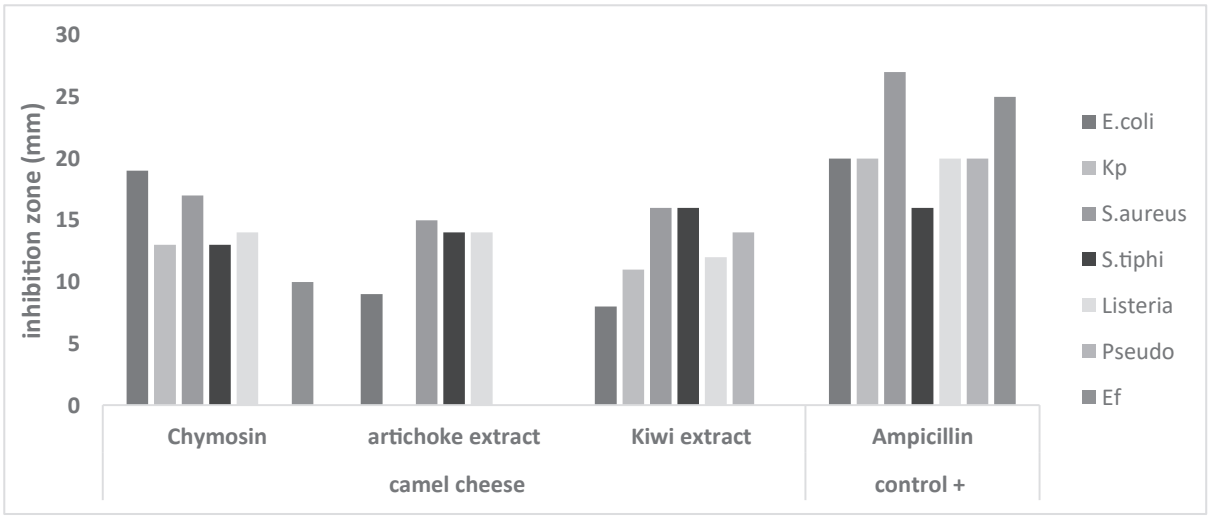

Figure 4. Antibacterial activity of camel cheese against 7 pathogenic strains (*E. coli*; *Klebsiella pneumonia*: Kp; *S. aureus*; *Salmonella tiphi*; *Listeria inocua*; *Pseudomonas aeruginosa*; *Enterococcus feacalis*).

According to Fig. 4, the majority of the samples show an inhibitory activity, more or less pronounced, on all the pathogenic bacteria.

These results indicate that our samples contain inhibitory substances with antibacterial activity. All the samples do not present the same spectrum of action against pathogenic bacteria.

The different types of camel cheese exhibit broad-spectrum inhibition against most pathogenic bacteria. The greatest activity was showed in camel cheese with chymosin against *Escherchia coli* (19 mm) and with kiwi extract against *Staphylococcus aureus* (16 mm). The lowest activity was observed with artichoke and kiwi extract against *Escherchia coli* (9 mm and 8 mm respectively). This activity is due to the presence of a protective system in camel milk, represented mainly by fairly high levels of antimicrobial factors such as lactoferrin, lysozyme, immunoglobulins and lactoperoxidase (Agrawal et al. 2004).

Conclusion

Based on the current body of evidence reviewed, camel milk-derived dairy products such as yoghurt and cheese demonstrate significant antimicrobial and antioxidant activities. These health-promoting effects are largely attributed to the presence of bioactive casein fractions, whey proteins (including lactoferrin and immunoglobulins), and probiotic lactic acid bacteria (LAB) naturally occurring or introduced during fermentation.

Despite these promising findings, most available studies remain in vitro or animal-based, and there is a clear need for comprehensive clinical trials to validate these functional claims in humans. Additionally, standardization of processing techniques—especially for fermented products like yoghurt and cheese—is essential to preserve and enhance these biofunctional properties while ensuring product safety, quality, and consumer acceptance.

Therefore, camel milk and its fermented products represent a valuable area for future research, particularly in the context of functional foods, nutraceuticals, and dietary strategies for health promotion and disease prevention.

Data availability

The data that supported the findings of this study are available from the corresponding authors upon reason-able request.

Conflict of interest

The authors stated that they had no conflict of interest to declare.

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