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Camel Milk Composition and Microbial Reduction with Different Pasteurization Methods

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Abstract The objective of this study was to investigate the efficacy of different thermal pasteurization methods on (1) the survival of the total aerobic bacteria, *E. coli* O157: H7, in camel milk, and (2) the camel milk components such as the fatty acid profile, lipid peroxidation, protein fractions, and the composition of volatile compounds. Samples of camel milk (N=9) were pasteurized at 65°C/30 min (PAST-1), 72°C/5 min (PAST-2), and 80°C/15 min (PAST-3). The survival of *E. coli* O157: H7 was evaluated using the traditional plate count agar (PCA) method while the total aerobic bacteria were enumerated using the petrifilm aerobic count plates (ACP). Complete elimination ($P<0.05$) of the total aerobic bacteria were achieved using PAST-1 and PAST-3 methods but not PAST-2 (3.4 $\log_{10}$ CFU/ml reduction). All pasteurization methods had a significant ($P<0.05$) bactericidal effect on *E. coli* O157: H7 resulting in a 6 $\log_{10}$ CFU/ml reduction. There were no significant ($P>0.05$) differences in the fatty acid profile including the *cis*-9, *trans*-11 conjugated linoleic acid (CLA), and *trans*-10, *cis*-12 CLA, and the lipid peroxidation products between raw and pasteurized milk samples. The milk protein profile was marginally altered by PAST-2 and PAST-3 treatments but not PAST-1. Thirty-four volatile compounds (VCs) were detected in the raw milk samples compared to 29 VCs in the pasteurized milk samples. Pasteurization treatments altered the concentrations of some milk VCs, increasing the Heptanal, Tridecanal, and Undecanal while decreasing the 2-Decanal and 2-Undecanal. This study shows that PAST-1 and PAST-3 treatments are more effective than PAST-2 at inactivating total aerobic bacteria. Additionally, the absence of significant changes in milk compositions indicates that PAST-1 and PAST-3 could be applied without affecting the nutritional value of camel milk.

Keywords: *camel milk, pasteurization, bacteria, milk composition*

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1. Introduction

Camel milk has traditionally been the main source of milk in some parts of the world, especially in the dry areas of Africa and Asia. Both camel and bovine milk share most of the essential nutrients, however, some antimicrobial factors, such as lactoferrin immunoglobulin G (IgG), and lysozyme are reported to be greater in camel milk [1]. Studies have reported various medicinal properties of camel milk against diabetes [2], hepatitis [3], allergies [4], autism [5], and lactose intolerance [6].

Milk and other unpasteurized dairy products are often reported to be associated with foodborne diseases. External contamination is the primary source of spoilage and pathogenic microorganisms in raw milk. One of the most prevalent serotypes of enterohemorrhagic *Escherichia coli* strains capable of producing Shiga toxin is *E. coli* O157:H 7 and responsible for about 36% of human clinical cases in North America [7,8]. The consumption of pasteurized milk contaminated with *E. coli* O157: H7 is the main concern to the dairy industry due to its critical clinical consequences even in a low infective dose. For instance, an *E. coli* O157: H7 outbreak (over a hundred people) caused by post prosess contamination was reported by [9] associated with consumption of pasteurized milk.

The dairy industry commonly uses the traditional pasteurization methods to prevent microbial contamination and enhance the shelf life of milk. However, the process of pasteurization may change the nutritional, sensory, and physicochemical properties of milk [10]. Compared to bovine milk, camel milk has poor heat stability at 100-140°C [11]. In addition, a recent study reported that the industrial processing methods negatively affects camel milk compositions, nutritional values, and health benefits [12]. However, the effects of thermal treatments at lower temperatures (65°C-80°C) on the microbial content and camel milk components, have not been extensively studied. Therefore, The goal of this study was to see how different

thermal pasteurization procedures affected the survival of the total aerobic bacteria and *E. coli* O157: H7, lipid peroxidation, protein fractions, fatty acid profile, and volatile compounds of camel milk.

2. Materials and Methods

2.1. Bacterial Strains

The activation of *E. coli* O157: H7 (NCTC strain 12900) was done according to the guideline of the manufacturer. A 1 ml of the culture stock was mixed with 10 ml of tryptic soy broth (TSB) (Difco Laboratories, Detroit, MI, USA) and then incubated at 37°C for 24 h. A 10 µl of loop inocula from the previous culture was then transferred into 9 ml of TSB and then incubated for 18 - 24 h at 37°C to allow enough time for the stationary phase to be reached.

Bacterial concentration was determined according to [13] by measuring the optical density at 600 nm (OD600) using the GENESYS 2 Spectrophotometer (Thermo Spectronic, New York, USA). Bacterial concentration was then determined using a conversion value of 0.01 OD600 to 8.0×10^6 colony-forming unit/ml (CFU/ml). The cell suspension of *E. coli* O157: H7 was added to the milk samples to provide ≈ 6 $\log_{10}$ CFU/ml (1×10^6 CFU/ml).

In addition, a non-pathogenic *E. coli* O157: H7 (ATCC 43888, Manassas, VA, USA) was cultured at 37°C in Luria-Bertani broth (Becton Dickinson, Sparks, MD, USA) within an orbital shaker at 250 rpm. The *E. coli* strain was then transformed through electroporation of pXen5-luxCDABE for bioluminescence emission (Caliper life sciences, Hopkinton, MA, USA) as previously prescribed [14].

2.2. Thermal Pasteurization

Raw milk samples (N = 9) in sterile bottles (250 ml) were purchased from a local camel farm and aliquots were immediately transported to the laboratory in an ice-cooled box. Three different thermal pasteurization methods were applied to raw milk samples (75 ml in 100 ml glass tube): heated in a water bath at 65°C for 30 min (PAST-1) [15]; 72°C for 5 min (PAST-2) [16]; and 80°C for 15 min (PAST-3) [17]. Following treatments, the resulting pasteurized milk was placed within an ice bath and cooled immediately to 4-6°C. Then, 1 ml of the control (raw milk) and 1 ml of the pasteurized milk samples were serially diluted (10^{-1} to 10^{-4}) with phosphate-buffered saline (0.2 M, pH 7.5). Each dilution was plated in triplicate on an aerobic count plate petrifilm (ACP) (3M, St. Paul, MN, USA) for total viable count estimation. For components analysis, an additional 15 ml were collected from the control and pasteurized milk samples and stored at -20°C until used.

To determine the CFU of *E. coli* O157: H7 and under sterile conditions, one ml of the bacterial suspension was added to the pasteurized milk samples to yield an approximate 10^6 CFU/ml (control). Once the pasteurization treatments (PAST-1, PAST-2, and PAST-3) had been applied, inoculated (control) and pasteurized milk samples were serially diluted and plated in triplicate on selective chromogenic medium HicromeTM (Sigma-Aldrich, St. Louis, USA). Each experiment was repeated three times for replications.

2.3. Bacterial Analysis

2.3.1. Bacterial Growth Evaluation

Control and pasteurized milk samples on ACP petrifilm were incubated at 37°C for 24 h, and then read using 3M Petrifilm Plate Reader (Model 6499, St. Paul, MN, USA). The viability of *E. coli* O157: H7 in all milk samples was evaluated using the standard plate count method. Following a tenfold dilution on the control and pasteurized milk samples that were inoculated with *E. coli* O157: H7, 100 µl from each diluted sample were spread on chromogenic medium HicromeTM (Sigma-Aldrich, St. Louis, USA) plates. All plates were incubated at 37°C for 24 h and bacterial colonies were counted based on CFU/ml. The microbiological analyses for each pasteurization treatment were run in triplicate.

To study the efficacy of using *in vivo* imaging system (IVIS) for real-time monitoring of the bacterial reduction in milk, an aliquot (1 ml) of bioluminescence *E. coli* O157: H7 was added to the pasteurized camel milk samples, under aseptic conditions, to yield an approximate 10^6 CFU/ml (control). The milk was then pasteurized using the PAST-3 method and inoculated (control) and pasteurized samples were serially diluted and plated in triplicate into sterile glass screw-capped test tubes (85 mm x 20 mm). To visualize the survival bacteria, the bioluminescence intensity of *E. coli* O157: H7 before and after pasteurization were measured with an IVIS in photon per second (p/sec).

2.4. Components Analyses

Milk samples were analyzed before and after pasteurization treatments to see how pasteurization affected milk protein fractions, lipid oxidation, fatty acids, and volatile compounds. The total protein of the milk samples was quantified using Pierce Coomassie plus assay kit (Thermo Fisher Scientific, Waltham, Maryland, USA), normalized amongst milk samples, and equivalent amounts were mixed with the NuPage LDS loading buffer and incubated for 10 min at 70°C. Thereafter, protein samples were resolved on a 4-12% sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE; Bis-Tris Nupage Mini Gel-Thermo Fisher Scientific, Waltham, MA, USA). A molecular weight marker (17 kDa to 170 kDa) was also loaded onto the gel for the identification of the molecular weight of the unknown proteins of milk samples (Fisher's EZ-Run Pre-stained Protein Marker). All gels were then stained with Coomassie brilliant blue R-250 staining solution (Bio-Rad, Hercules, CA, USA) to visualize the protein bands. The analyses for lipid oxidation, fatty acids, and volatile compounds were as previously prescribed [18].

2.5. Statistical Analysis

Our data was statistically analyzed using JMP software (Version pro 14.0). A one-way ANOVA was used to analyze data (i. e determine differences among groups) and Tukey's test was used to compare means at the 0.05 level.

3. Results

3.1. Microbiological Analysis of Camel Milk before and after Pasteurization

Before pasteurization, the total viable bacterial count mean of the raw camel milk samples was 5.7 $\log_{10}$ CFU/ml for the three replicates. The standard plate count on ACP petrifilm revealed 3.4 $\log_{10}$ CFU/ml reduction in total aerobic bacteria was achieved using the PAST-2 treatment whereas no survival cells were detected with the PAST-1 and PAST-3 treatments Table 1. In addition, the initial bacterial population of *E. coli* O157: H7 was 6 $\log_{10}$ CFU/ml before pasteurization, and no viable *E. coli* O157: H7 were isolated from the thermally treated milk samples Table 1.

Table 1. Effect of different pasteurization methods on the surviving of total viable count and *E. coli* O157: H7 in camel milk

Bacterial strains	Count ($\log_{10}$ CFU/mL)			
	Control	PAST-1	PAST-2	PAST-3
Total viable count	5.7 ^{a}	ND ^{c}	2.3 ^{b}	ND ^{c}
E. coli O157: H7	6.0 ^{a}	ND ^{b}	ND ^{b}	ND ^{b}

Different lowercase letters within the same row denote significant differences among means at P<0.05. ND not detected (detection limit is < 1 CFU/ml). PAST-1 = 65°C/30 min, PAST-2 = 72°C/5 min, and PAST-3 = 80°C/15 min.

3.2. Bioluminescent *E. coli* O157: H7

The survival of bioluminescent *E. coli* O157: H7 in camel milk samples subjected to the PAST-3 treatment was monitored using the IVIS imaging system. Compared to the control, the concentration of bioluminescence in *E. coli* O157: H7 decreased (P<0.05) in the pasteurized milk samples. The emission of bioluminescence in the *E. coli* O157: H7 averaged 4.87E+08 p/s in the control milk compared to 1.20E+05 p/s in the pasteurized milk samples Figure 1.

3.3. Impact of Different Pasteurization Methods on Camel Milk Components

3.3.1. Fatty Acid Profile

The effect of pasteurization methods on fatty acids concentration in the camel milk samples is presented in Table 2. Except for a reduction (P<0.05) in oleic acid (C18:1c9), no changes (P>0.05) were observed between the raw (control) and the pasteurized milk samples. No differences (P>0.05) were also observed between the raw and the pasteurized milk samples in their conjugated linoleic acids (CLA) content (*cis*-9, *trans*-11 CLA and *trans*-10, *cis*-12 CLA) (Figure 2 & Figure 3).

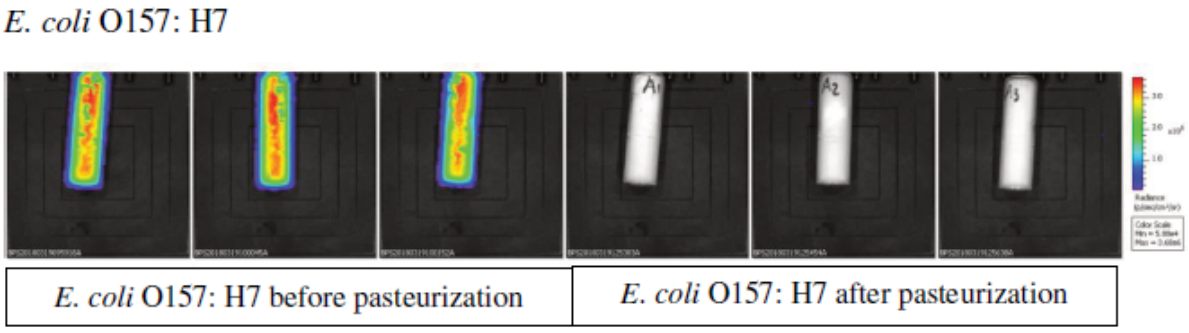

Figure 1. Quantification of bioluminescent *E. coli* O157: H7 in camel milk before and after pasteurization

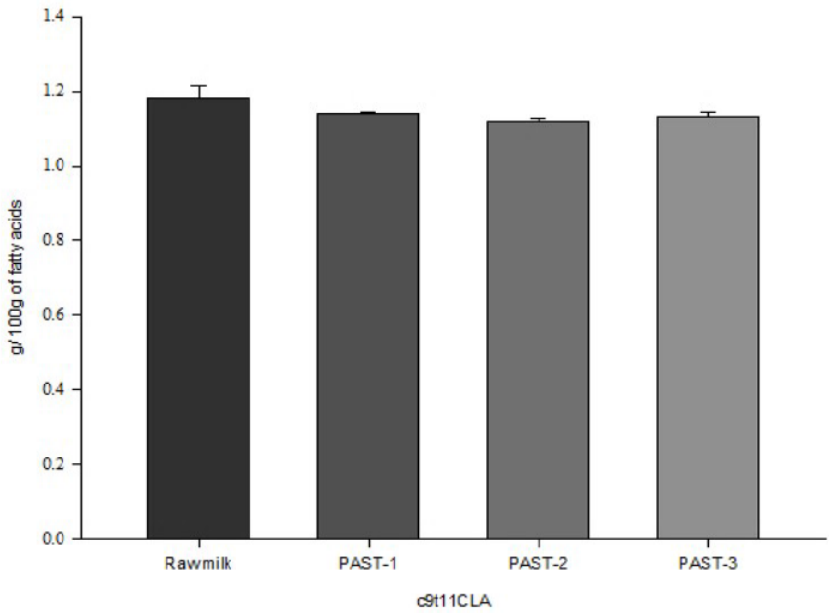

Figure 2. Effect of different pasteurization methods on *cis*-9, *trans*-11, CLA in raw camel milk. PAST-1 = 65°C/30 min, PAST-2 = 72°C/5 min, and PAST-3 = 80°C/15 min

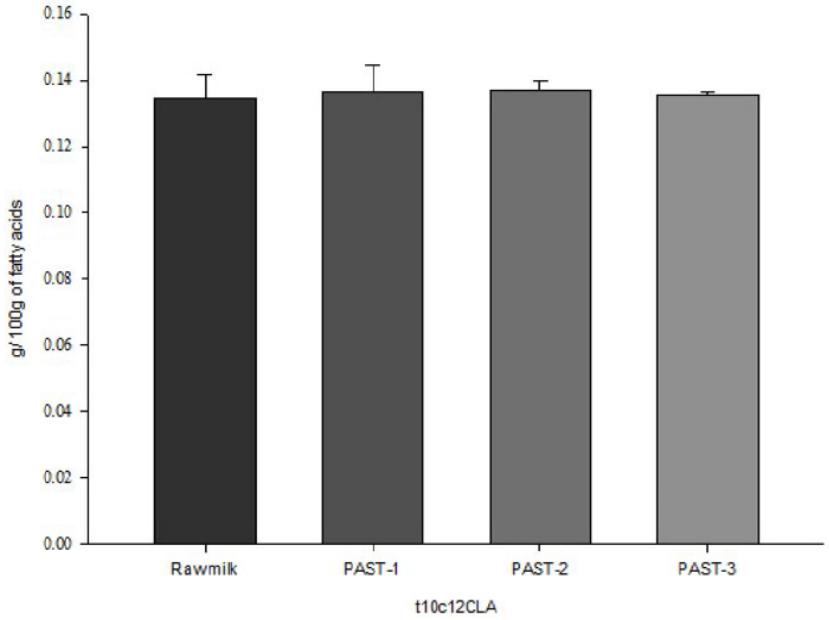

Figure 3. Effect of different pasteurization methods on *trans*-10, *cis*-12, CLA in raw camel milk. PAST-1 = 65°C/30 min, PAST-2 = 72°C/5 min, and PAST-3 = 80°C/15 min

3.3.2. Lipid Oxidation

The thiobarbituric acid reactive substances (TBARS) values were the same in the raw and pasteurized milk samples, with no changes (P>0.05) among the different treatments Figure 4.

Table 2. Fatty acids profile (g/100g fatty acids) for raw and pasteurized camel milk

Fatty acid	Raw milk	PAST-1	PAST-2	PAST-3	SEM
C6:0	0.33	0.27	0.35	0.33	0.025
C8:0	0.36	0.28	0.34	0.33	0.022
C10:0	0.23	0.21	0.24	0.23	0.010
C12:0	0.86	0.83	0.86	0.86	0.015
C14:0	9.61	9.45	9.63	9.73	0.068
C14:1	0.79	0.77	0.78	0.78	0.015
C16:0	22.81	22.85	22.49	22.53	0.104
C16:1	5.15	5.12	5.12	5.12	0.036
C18:0	17.71	18.14	17.82	17.70	0.137
C18:1*trans*	5.65	5.33	5.22	5.45	0.134
C18:1c9	20.75 [a]	20.72 [a]	20.45 [b]	20.51 [b]	0.063
C18:1c11	0.43	0.42	0.42	0.41	0.003
C18:2n6	3.74	3.73	3.69	3.71	0.016
C18:2t9t12	0.12	0.12	0.12	0.11	0.002
C18:3n6	0.38	0.39	0.38	0.38	0.002
C18:3n3	0.54	0.53	0.53	0.53	0.002
C20:1n9	0.07	0.07	0.07	0.08	0.005
C20:4n6	0.21	0.21	0.21	0.21	0.002
C20:5n3 (EPA)	0.03	0.03	0.05	0.06	0.014
C22:5n3	0.08	0.12	0.17	0.17	0.027
C22:6n3 (DHA)	0.01	0.05	0.03	0.018	0.010

Different lowercase letters within the same row denote significant differences among means at P < 0.05. PAST-1 = 65ºC/30 min, PAST-2 = 72°C/5 min, and PAST-3 = 80°C/15 min. EPA= Eicosapentaenoic Acid; DHA= Docosahexaenoic Acid.

3.3.3. Milk Protein

The SDS-PAGE electrophoresis shows qualitative differences in protein profiles of raw and treated milk samples (Figure 5). A total of 7 protein bands were separated with molecular weights (Mwt) of 15, 27, 50, 56, 65, 84, 164, and 200 kDa, roughly corresponding to alpha-lactalbumin (α-La), Casein proteins (Cas), Immunoglobulins (Ig), Camel serum albumin (CSA), Lactoferrin (LF), Uncharacterized protein, and Xanthine dehydrogenase/oxidase (XDO), respectively. PAST-1 caused no visible changes in the electrophoresis pattern compared to the control (raw milk). Increasing the temperature to 72°C with the PAST-2 treatment also resulted in no visible changes in the electrophoresis pattern except for increasing the intensity of the α-La (Mwt 15 kDa) band. At 80°C (PAST-3), the band intensity of LF (Mwt 84 kDa) became lighter while the band intensity of α-La (Mwt 15 kDa) increased Figure 5.

3.3.4. Volatile Compounds

Using mass spectral matching against the NIST library standards and retention index, a total of 34 VCs were identified (Table 3). Five VC (Octanal, 1-Octanol, Ethyl caprylate (octanoate), Decanoic acid, and 9-Hexadecenoic acid) disappeared after pasteurization. Ethyl caprate (decanoate) and Ethyl laurate (dodecanoate) were detected only in the raw and the PAST-1 treatment, while β-Hydroxydodecanoic acid was detected in the raw and the PAST-3 treatment. Compared to the raw milk, pasteurization increased (P<0.05) the formation of Heptanal and decreased the formation of 2-Decanal, 2-Undecanal, and Nonanoic acid, particularly with the PAST-2 and PAST-3 treatments. Compared to the raw milk, the formation of Tridecanal and Undecanal increased only with the PAST-1 treatment. Pasteurization treatments had no effects (P>0.05) on the remaining 19 VCs.

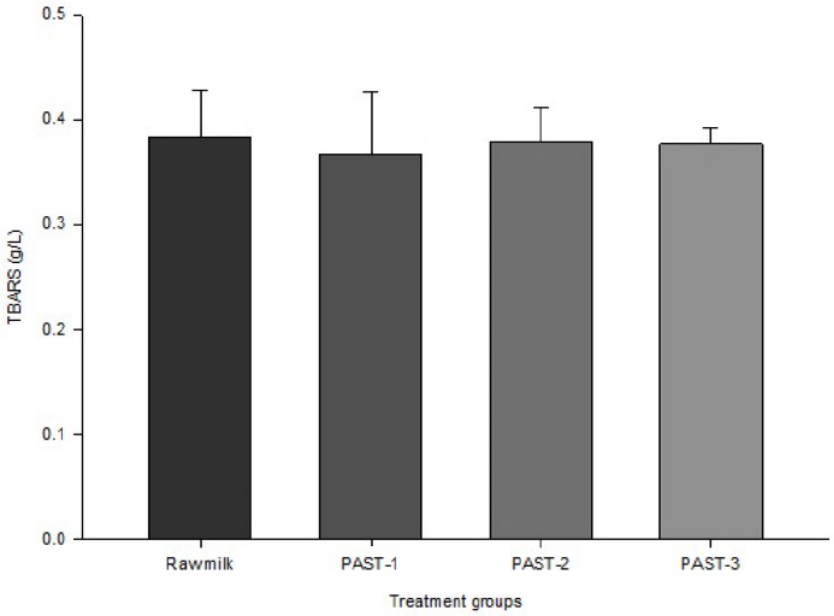

Figure 4. Effect of different pasteurization methods on TBARS in raw camel milk. PAST-1 = 65°C/30 min, PAST-2 = 72°C/5 min, and PAST-3= 80°C/15 min

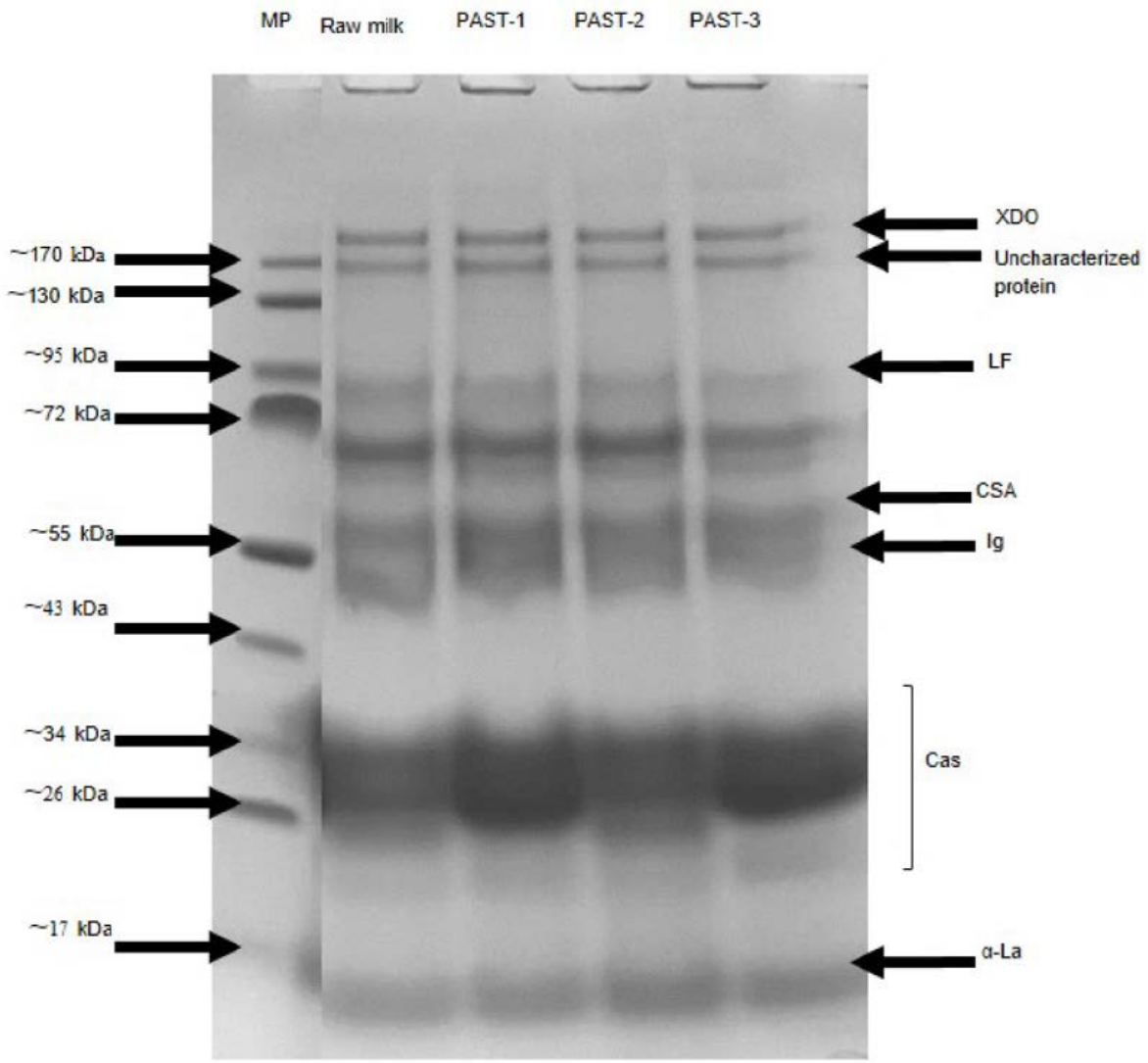

Figure 5. Effect of different pasteurization methods on protein fractions in camel milk.MP = milk protein; XOD = Xanthine dehydrogenase/oxidase; LF = Lactoferrin; CSA = Camel serum albumin; Ig = Immunoglobulins; Cas = Casein; and α-La = alpha- Lactalbumin. PAST-1 = 65°C/30 min, PAST-2 = 72°C/5 min, and PAST-3 = 80°C/15 min

Table 3. Volatile organic compounds for raw and pasteurized camel milk

Compound Name	LRI	Raw milk	PAST-1	PAST-2	PAST-3	P-value
Hexanal	7.42E+02	1.83E+07[A]	2.36E+07	2.16E+07	4.00E+07	0.40
2-Furanmethanol	8.33E+02	2.26E+06	1.94E+06	3.55E+06	2.81E+06	0.88
Heptanal	8.73E+02	4.07E+06[b]	1.47E+07[ab]	1.81E+07[a]	2.28E+07[a]	0.04
Oxime- methoxy-phenyl	8.75E+02	3.18E+07	3.72E+07	3.68E+07	4.77E+07	0.60
1-Heptanol	9.42E+02	4.60E+06	5.91E+06	3.66E+06	ND	0.22
Octanal	9.72E+02	4.79E+07[a]	ND[b]	ND[b]	ND[b]	0.01
Benzyl alcohol	1.00E+03	9.83E+06	9.78E+06	1.07E+07	9.01E+06	0.63
2-Octenal	1.02E+03	1.74E+07	1.74E+07	1.49E+07	1.47E+07	0.39
1-Octanol	1.04E+03	6.42E+06[a]	ND[b]	ND[b]	ND[b]	0.01
4-Methylbenzaldehyde	1.05E+03	1.34E+07	1.66E+07	2.15E+07	2.58E+07	0.18
Nonanal	1.08E+03	3.59E+07	3.54E+07	3.08E+07	3.14E+07	0.46
2-Nonenal	1.13E+03	1.96E+07	1.97E+07	1.54E+07	1.38E+07	0.06
Octanoic acid	1.14E+03	6.09E+06	7.54E+06	3.59E+06	ND	0.07
Methyl salicylate	1.17E+03	2.10E+07	1.98E+07	ND	3.02E+07	0.10
Ethyl caprylate (octanoate)	1.17E+03	2.52E+06[a]	ND[b]	ND[b]	ND[b]	0.01
Decanal	1.18E+03	9.31E+06	9.96E+06	8.92E+06	7.76E+07	0.06
2-Decanal	1.22E+03	3.19E+07[a]	2.96E+07[a]	2.47E+07[b]	2.21E+07[b]	0.01
Nonanoic acid	1.23E+03	2.80E+07[a]	2.57E+07[a]	1.60E+07[ab]	6.63E+06[b]	0.01
Undecanal	1.28E+03	7.21E+06[b]	8.90E+06[a]	7.59E+06[ab]	6.59E+06[b]	0.01
2-Undecanal	1.34E+03	3.72E+07[a]	3.42E+07[a]	2.67E+07[b]	2.31E+07[b]	0.01
Decanoic acid	1.34E+03	4.10E+06[a]	ND[b]	ND[b]	ND[b]	0.01
Ethyl caprate (decanoate)	1.36E+03	4.92E+06[a]	2.80E+06[b]	ND[c]	ND[c]	0.01
Dodecanal	1.38E+03	7.60E+06[ab]	8.81E+06[a]	7.29E+06[ab]	6.31E+06[b]	0.01
Tridecanal	1.47E+03	4.13E+06[b]	5.33E+06[a]	4.61E+06[ab]	4.39E+06[b]	0.01
Ethyl laurate (dodecanoate)	1.55E+03	2.06E+06[a]	1.66E+06[b]	ND[c]	ND[c]	0.01
Tetradecanal	1.56E+03	3.97E+06	5.01E+06	4.51E+06	4.44E+06	0.12
Decyl decanoate	1.61E+03	7.75E+06	9.20E+06	8.10E+06	7.55E+06	0.14
2-Pentadecanone	1.67E+03	1.04E+07	1.44E+07	1.11E+07	1.44E+07	0.59
β-Hydroxydodecanoic acid	1.69E+03	4.15E+06[a]	ND[b]	ND[b]	5.35E+06[a]	0.01
Tetradecanoic acid	1.74E+03	6.32E+06	8.64E+06	6.57E+06	7.22E+06	0.69
Hexadecanal	1.79E+03	2.98E+06	3.39E+06	2.73E+06	3.78E+06	0.49
2-Heptadecanone	1.87E+03	3.12E+06	4.87E+06	3.64E+06	4.82E+06	0.35
Hexadecanoic acid	1.94E+03	1.27E+07	1.87E+07	1.51E+07	1.70E+07	0.67
9-Hexadecenoic acid	2.05E+03	1.25E+07[a]	ND[b]	ND[b]	ND[b]	0.01
Oleic Acid	2.12E+03	2.33E+06	6.46E+06	3.23E+06	1.66E+07	0.06

[A] The data is representative of the area underneath the curve.
ND: not detected within the sample.

4. Discussion

Although milk pasteurization using thermal treatment has been reported to minimize microbial contamination and enhance shelf life, the thermal applications may have undesirable effects on different nutrients and chemical components of milk. The current study was undertaken to investigate the effects of different thermal treatment-based pasteurization methods on camel milk components, and the survivability of *E. coli* O157: H7 and total aerobic bacteria. As the data indicate, PAST-1 treatment is highly effective against total and *E. coli* O157: H7 bacteria in camel milk. Similar findings were reported by [19] and [15], who carried out holder pasteurization (63°C for 30 min) in human and camel milk, respectively. However, [20] reported a residual population of *Mycobacterium paratuberculosis* in the heated bovine milk at 65 °C for 30 min using a laboratory-scale pasteurizer unit. Our results revealed that PAST-3 caused complete inactivation of both *E. coli* O157: H7 and total aerobic bacteria. Although PAST-2 was not completely effective against the total viable count (only 3.4 $\log_{10}$ reduction), it was effective in the complete inactivation of *E. coli* O157: H7. The effects of PAST-2 and PAST-3 on camel milk composition and the preparation of fermented camel milk were reported previously [16,17,21], however, the antimicrobial effects of these two thermal treatments are lacking in camel milk. To our knowledge, this study is the first one that reports these findings.

In this study, the use of the IVIS imaging approach allowed real-time monitoring of the bacterial activity and providing a better sense of the bacterial presence on samples. This imaging technique has been used in previous works to assess the presence of bacteria in meats [22] or the bactericidal effects of nanoparticles [23]. In the present study, the IVIS was successfully used to validate the bactericidal effect of camel milk pasteurization. Understanding that bioluminescence cannot be used in a routine with wild and not transformed bacteria, the IVIS indicates the detected bacteria in the complex milk sample was decreased to a not detectable level after pasteurization, as also determined with the (CFU /ml) counts.

Except for a slight reduction in C18:1c9 with PAST-2 and PAST-3, no significant differences in fatty acid concentrations were found between the raw and pasteurized milk samples indicating that milk fatty acids

were not affected by the different pasteurization methods. The fatty acid profile of humans [24] and camel milk [25] were not significantly altered by holder pasteurization (62.5-63°C for 30 min). Additionally, both [26] and [27] obtained similar results in bovine and goat milk subjected to high-temperature, short time (HTST) pasteurization (72°C for 15 sec), respectively. Furthermore, no significant changes in the CLA were observed in the current study between the pasteurized and control samples (Figure 2 and Figure 3). These results are consistent with an earlier study by [28], who reported that the CLA content of bovine milk was not affected by thermal processing at different pasteurization temperatures. Contrarily, [29] reported a significant increase in the *cis*-9, *trans*-11 CLA after pasteurizing sheep milk at 73°C for 5 sec, while [30] reported a significant decrease in the *cis*-9, *trans*-11 CLA content of bovine milk (2% total fat) after HTST pasteurization (77.2°C for 16 sec). These differences could be attributed to differences in processing conditions (milk temperature and holding time) and/or milk types (bovine vs. sheep milk).

Malondialdehyde (MDA), a secondary product of autoxidation, was measured using the TBARS assay. Consistent with the fatty acid profile findings, our pasteurization methods (PAST-1, PAST-2, and PAST-3) did not significantly change the TBARS values of camel milk. Our results are in agreement with the findings of [31], who reported no significant differences in MDA concentration of human milk subjected to holder pasteurization (63 °C for 30 min). Similarly, [32] reported no significant changes in TBARS values of raw bovine milk subjected to industrial heat treatments.

In the current study, milk proteins were separated by using a one-dimensional SDS-PAGE. There were no noticeable differences between the electrophoresis patterns of raw and PAST-1 milk samples (Figure 5). This result is in accordance with [33] who did not find any differences in the electrophoresis pattern of the camel milk heated at 65 °C for 30 min. Another study reported no effect of the thermal treatments below 70°C on camel whey proteins [34]. The increased intensity of the band corresponding to α-La was the only visible change under the PAST-2 treatment (Figure 5). A similar result was obtained by [35], who reported increases in the α-La intensity of camel milk with heating from 60-130 °C for 30 min. In contrast to earlier findings, however, [33] reported that α-La was not affected by heating camel milk at 75 °C for 30 min. In addition, a decrease in the intensity of the LF band (Mwt 84 kDa) was observed in this study after applying the PAST-3 method (Figure 5). Our results are in contrast to the findings of [36] and [35] who reported no effects on camel LF at 85 °C for 15 and 30 min while, a slight disappearance of LF after heating camel milk at 100 °C for 30 min. In the current study, CSA was not affected by all pasteurization methods in agreement with [33] who reported no changes in the electrophoresis pattern of CSA when camel milk was heated at 75°C for 30 min. A significant diminishing of CSA, however, was reported by [37] when camel milk was heated at 80°C for 60 min, while [34] reported the complete disappearance of CSA when camel milk was heated at 80°C for 30 min.

Aldehydes in raw milk are formed either during lipid oxidation [38] or by transferring to milk through the consumed feeds [39]. The volatile compounds profiles of milk in the current study showed an increase in some aldehydes (Heptanal, Tridecanal, and Undecanal) following the pasteurization treatments. Similar increases in the total aldehydes were reported by [40] who investigated the effect of industrial processing methods such as HTST (75°C for 15 sec) and ultra-high temperature (140°C for 3 sec) on the volatile compounds of skimmed camel milk. Reference [41] also reported an increase in aldehydes content after subjecting bovine milk to HTST (75°C for 15 sec). Similarly, treated human milk with high-pressure thermal processing resulted in an increase in the aldehydes content [42]. On the other hand, some other aldehyde compounds (2-Decanal and 2-Undecanal) significantly decreased ($P<0.05$) following pasteurization treatments. This finding is in agreement with the results of [43] who reported pasteurization (72°C for 15 sec) decreased the levels of some aldehydes in Spanish ewe milk.

5. Conclusions

The present study has shown that both the PAST-1 and PAST-3 methods have better bactericidal effects against the total viable count than the PAST-2 method. A 6-$\log_{10}$ reduction in *E. coli* O157: H7 was reported in all pasteurized milk samples. This research also revealed that camel milk protein fractions, lipid peroxides, and fatty acids were not significantly affected by pasteurization treatments. However, the concentrations of some milk aldehydes were altered after pasteurization. The present findings will be useful to the camel dairy processors for optimal pasteurization of dairy products.

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