ABSTRACT

Making cheese from camel milk (CM) presents various challenges due to its different physicochemical properties compared with bovine milk (BM). In this study, we investigated the chemical composition, proteolysis, meltability, oiling off, texture profile, color, microstructure, and rheological properties of low-fat Cheddar cheese (LFCC) prepared from BM-CM blends. LFCC was produced from BM or BM supplemented with 15% CM (CM15) and 30% CM (CM30), and analyzed after 14, 60, 120, and 180 d of ripening at 8°C. Except for salt content, no significant differences (P > 0.05) were observed between LFCC BM CM15 and CM30. The addition of CM increased the meltability and oiling off in the resultant cheese throughout storage. After melting, LFCC CM30 showed lower L* values than LFCC made from BM and CM15, while a* and b* values exhibited higher values than BM and CM15 samples. LFCC from CM30 also exhibited lower hardness compared with other treatments. Moreover, LFCC made from BM showed a rough granular surface, while cheese samples made from BM-CM blends exhibited a smooth surface. The rheological parameters, including storage modulus, loss modulus, and loss tangent varied among cheese treatments. The determined acetoin and short-chained volatile acids (C2-C6) in LFCC were affected by the use of CM, since CM15 showed significantly higher amounts than BM and CM30, respectively. The detailed interactions between BM and CM in the cheese matrix should be further investigated.

Keywords: camel milk, low-fat Cheddar cheese, proteolysis, rheological properties, texture, volatile compounds

INTRODUCTION

Cheese production from camel milk (CM) poses certain challenges such as longer clotting time, partial rennet action, weak coagulum, lower yield, and longer fermentation time (Baig et al., 2022). Compared with bovine milk (BM), CM has a lower total solids content but a higher content of lysozyme, lactoferrin, immunoglobulins and total salts, including potassium, chloride, calcium, phosphorus, and sodium (Park, Haenlein and Wendorff, 2017, Shamsia, 2009). The protein, fat, and carbohydrate contents in CM range between 2.7 and 4.8 g/100 g, 3.1–4.2 g/100 g, and 4.0–4.8 g/100 g, respectively (Hailu et al., 2016, Mohamed et al., 2021). Additionally, the diameter of CM casein micelles is larger than that of BM casein micelles (Hailu et al., 2016). Casein fractions in CM are presented in the following sequence; β- > αS1- > αS2- > κ-casein, whereas in BM, they are presented as follow; αS1- > β- > κ- > αS2-casein (Fox et al., 2015). In CM, κ-casein represents 3.3% of the total casein content, whereas in BM, it represents 13% of the total casein (Hailu et al., 2016). Casein fractions in CM were presented in the following sequence: β- > αS1- > αS2- > κ-casein, whereas in BM, they are presented as follow: αS1- > β- > κ- > αS2-casein (Fox et al., 2015). In CM, κ-casein represents 3.3% of the total casein content, whereas in BM, it represents 13% of the total casein (Hailu et al., 2016). In addition, α-lactalbumin is the major whey protein in CM, while β-lactoglobulin is the predominant whey protein in BM (Hailu et al., 2016).

Cheese is a major dairy product, but the production of cheese from CM remains challenging. Currently, there are no commercially available CM cheeses, and most research findings are limited to unripened soft cheese prepared with mesophilic starter cultures, bovine chymosin, and high cooking temperatures (Hailu et al., 2018, Walle et al., 2017). Using CM for cheese produc-
tion would help conserve nutrients and enhance the beneficial aspects of CM throughout ripening (Baig et al., 2022). Numerous approaches have been developed to prepare cheese from CM, including heat treatment, starter cultures, salting, and the addition of rennet and calcium chloride (Abou-Soliman, Awad and El-Sayed, 2020, Bekele et al., 2019, El Zubeir and Jabreel, 2008, Konuppayeva et al., 2017). The addition of rennet and calcium chloride to CM resulted in coagulation, and a soft curd was obtained (Inayat et al., 2003). Certain cheese types were also prepared from CM using enzymes such as chymosin and proteases isolated from Withania coagulans or Ficus carica (El Zubeir and Jabreel, 2008, Mbye et al., 2022). The effect of chymosin concentration on cheese yield, organoleptic properties, and microbiological quality has been evaluated (Türkmen and Güler, 2022). CM cheese was produced using different levels of camel chymosin with an activity of 1000 IMCU/mL, while a starter culture comprising Lactobacillus bulgaricus ssp. delbrueckii and Streptococcus thermophilus was effective in acidifying CM, facilitating rennet activity for coagulation (Walle et al., 2017). Additionally, unripened soft cheese was also prepared from CM, and it was observed that increasing the cooking temperature of cheese curd resulted in a higher total solids content and acceptance than slightly cooked cheese (Walle et al., 2017).

Cheddar cheese is a highly nutritious dairy product that provides significant amounts of dietary protein and calcium. However, due to its high fat content, consumption of full-fat Cheddar cheese can contribute to high levels of dietary fats. To address this, the production of low-fat Cheddar cheese (LFCC) has been attempted, but achieving a texture and flavor similar to full-fat cheese remains a challenge (Amelia et al., 2013). Nonetheless, progress has been made in the manufacture of low- or reduced-fat cheese, with some commercial varieties containing up to 75% less fat than traditional Cheddar cheese (Schepers, 2005). However, LFCC with more than 82% fat reduction has yet to be made available in the market due to issues with texture and flavor defects associated with substantial fat reduction (Amelia et al., 2013).

Challenges in producing cheese solely from CM have led to the exploration of blending CM with BM to produce commercial cheeses, such as Cheddar cheese. Because of the weaker cheese-making ability of some milk species compared with BM, the use of different ruminant milk species blends for cheese manufacture was previously reported (Abdalla et al., 2022a, Abdalla et al., 2022b, Ayvaz et al., 2021, Niro et al., 2014, Ocak, Javidipur and Tuncturk, 2015, Sant’Ana et al., 2013, Vyhmeister et al., 2019). This study aimed to investigate the characteristics of LFCC made from BM blended with different ratios of CM (15% and 30%). The resultant cheese was analyzed for chemical composition, proteolysis, meltability, oiling off, color, and texture. Additionally, the microstructure, rheological properties, and volatile compounds were evaluated at 60, 120, and 180 d of ripening at 8°C. To the best of our knowledge, this is the first attempt to use BM-CM blends to produce Cheddar cheese.

MATERIALS AND METHODS

Materials

Low-fat pasteurized BM (1.0% fat, 3.2% protein, and 4.6% carbohydrate) and CM (1.0% fat, 2.7% protein, and 4.2% carbohydrate) were purchased from a local dairy manufacturer (Al-Ain, UAE). In addition, fermentation-produced camel chymosin FAR-M, chymosin (2500 IMCU/g), and a Cheddar cheese starter culture DVS® RSF-736 (Streptococcus thermophilus, Lactococcus lactis ssp. cremoris, Lactococcus lactis ssp. Lactis, and Lactobacillus helveticus) were obtained from Chr. Hansen Holding A/S (Dubai, UAE). Unless otherwise mentioned, all reagents and chemicals were purchased from Sigma-Aldrich (St. Louis, MO, USA).

Low-Fat Cheddar Cheese Making

To determine the maximum level of CM that could be blended while still being able to maintain an acceptable curd, BM-CM blends (with CM ranges between 0 and 50%) were initially prepared, and renneting was evaluated by using camel chymosin. An acceptable curd firmness, comparable to that from BM was observed by blending BM with up to 30% of CM. LFCC cheese was prepared using BM alone (control) and by blending BM with 15% and 30% of CM (CM15 and CM30, respectively). LFCC making was carried out following the procedure detailed in (Ibáñez, Waldron and McSweeney, 2015, Li et al., 2022). Briefly, 12 L of pasteurized low-fat milk were placed in a temperature-controlled cheese vat and tempered for 30 min at 32°C. Cheddar cheese starter culture (0.03%, wt/wt) was added and allowed to incubate for 30 min, followed by the addition of 60 IMCU/L of camel chymosin. After 45 min, the coagulum was cut and cooked from 31 to 39°C over a period of 30 min and held at that temperature until the pH dropped to 6.2, after which the whey was drained from the vats. The curd was then cut into blocks and inverted every 15 min until the pH decreased to 5.4. The curd was milled into small pieces and salted at a level of 2.5% (wt/wt) NaCl and equilibrated for 20 min. The curds were then wrapped in cheesecloth and moved to molds and were pressed at a pressure of 2.5 kg/cm².
for 14 h. The cheeses were removed and vacuum-packed (99.9% air extracted). Samples were taken periodically during ripening at 8°C for up to 180 d. Two sets of LFCC treatments were prepared, each comprising 3 blocks made in triplicate.

**Chemical Composition**

Grated LFCC samples were used at d 14 for the analysis of moisture content using the oven-drying method at 105°C, fat content by using Gerber method, protein content using the Kjeldahl method, and ash content by using the muffle furnace method according to AOAC (2000). The content of salt in cheese samples was also determined (ISO5943: IDF88, 2006). In addition, the pH value was measured at 60, 120, and 180 d of ripening after homogenizing 25 g of grated cheese samples with 25 mL of distilled water, and using a digital pH meter Stater3100 (OHAUS Corp., Parsippany, NJ, USA).

**Proteolysis Assessment**

The water-soluble extract (WSE) of LFCC samples was prepared following Kuchroo and Fox (1982) method and adjusted to pH 4.6 using 1.0 N HCl followed by centrifugation at 6000 × g and 4°C for 15 min. The nitrogen content of the pH 4.6-water-soluble extract (pH 4.6-WSN) was determined by using the Kjeldahl method (AOAC, 2000), and the WSN-pH 4.6 was expressed as a ratio of the total nitrogen (TN %). Furthermore, 12% of trichloroacetic acid-soluble nitrogen (TCA-SN) was determined in the 9-mL filtrate obtained after the precipitation of the filtered WSE of LFCC with 24% TCA (1:1) to achieve 12% TCA as the final concentration. In addition, the protein patterns of the precipitates from the pH 4.6-WSE preparation precipitates were evaluated by sodium dodecyl-sulfate PAGE (SDS-PAGE) as described by Ong and Shah (2009) using dithiothreitol as the reducing agent, and 12% acrylamide separating gel was used for separation. The gel was scanned using Gel Doc XR+ and Chemidoc XRS+ Imaging Systems (Bio-Rad Laboratories Inc., Hercules, California, USA).

**Meltability and Oiling Off**

Meltability was performed by using Schreiber test and slightly modified by Altan, Turhan and Gunasekaran (2005). Briefly, the meltability test was accomplished by placing LFCC samples in a glass Petri dish, which was then covered with a lid. The covered samples were subjected to heating at a temperature of 232°C for 5 min. The meltability was determined by measuring the percentage increase in diameter compared with the unmelted samples.

The oiling off in LFCC was evaluated following the method of Wadhwani, McMannus and McMahon (2011), with slight modifications. Briefly, 18 g of grated cheese samples were transferred to a Gerber butyrometer and immersed for 15 min in boiling water to melt the samples. Afterward, 20 mL of methanol: distilled water mixture (1:2, at 57°C) were immediately added to the tubes, followed by centrifugation at 6,000 × g at room temperature for 10 min. The oiling off was determined as a percentage using the following formula:

\[
\text{Oiling off(\%)} = \frac{\text{Fat reading}}{\text{Cheese weight}} \times 100.
\]

**Color Parameters**

The color properties (L*, a*, and b* values) of the melted LFCC samples were determined by using Minolta Chroma-meter CR-300 (Minolta Corporation Ltd., Ramsey, NJ, USA). Three measurements were randomly recorded from the surface of melted LFCC samples stored at 8°C. L* value indicates sample lightness from black (0) to white (100), a* value signifies color varying from redness (+) to greenness (−), and b* value corresponds to yellowness to blueness.

**Microstructure by SEM**

The microstructure of LFCC samples after 60, 120, and 180 d of ripening was evaluated by scanning electron microscopy (SEM) as described by Abdalla et al. (2022a). Small cube (2 cm^3) of LFCC samples were placed on an aluminum holder and covered by a thin gold layer using a Cressington 108 Auto Sputter Coater (Ted Pella Inc., Redding, CA, USA). SEM analysis of the gold-covered LFCC samples was accomplished by JEOL JSM–6010LA (SEM, Akishima, Tokyo, Japan) working at 20 kV accelerating voltage.

**Rheological Properties**

For texture profile analysis, a cylindrical cheese sample (20 mm in height and 25 mm in diameter) was cut from the center of LFCC blocks. LFCC samples were collected from the center of cheese blocks and cut into 15-mm cubes using a sharp knife, covered by plastic to avoid the loss of water, and then kept at room temperature for 1 h before analysis. The texture profile analysis of LFCC was carried out at 60, 120, and 180 d according to the method of Ayyash et al. (2018). The texture
parameters hardness (the force needed to achieve a certain deformation of cheese sample), adhesiveness (the work needed to overcome the attractive forces between food surface and other materials surface contacting the food), cohesiveness (an index of how well cheese structure resists compression), springiness (the rate of deformed cheese returns back to its initial form after removing the deforming force), gumminess (the necessary energy to disintegrate cheese to be swallowed), and chewiness (the required energy to chew cheese) of duplicate samplings were assessed on the same day by using a Texture Analyzer CT3 (Brookfield AMETEK, Middleboro, MA, USA). The conditions of testing were TA11/1000-cylinder probe, a test speed of 0.4 mm/s, a pre-test speed of 1 mm/s, a compression 50% of the initial height, and 2 compression cycles.

Small deformation rheological properties of LFCC samples were determined in duplicate as described by Ayyash et al. (2018). The samples were collected 3 mm below the cheese blocks surface. Then, cheese samples were directly placed in a small airtight plastic container and allowed to equilibrate for at least 20 min at the room temperature. Discovery Hybrid Rheometer HR-2 (TA Instruments, New Castle, DE, USA) was used. The geometry comprised of 2 parallel plates with 40-mm diameter performing at a gap size of 2.6 mm (sample thickness). The unnecessary cheese was carefully trimmed, and the sample was permitted to rest on the rheometer for 1 min to relax the stress generated throughout the handling of sample.

The linear viscoelastic range was studied using a strain sweep (0.1–10%) at a frequency of 1.0 Hz. Then, a strain in the linear region (0.5%) was used for the frequency sweep test, where frequency differed from 0.1 to 20 Hz at 25°C. Storage modulus (G'), loss modulus (G''), and loss tangent (tan δ) were recorded. The rheological properties of the LFCC as a function of temperature were evaluated as reported by Fenelon, Beresford and Guinee (2002). LFCC samples were heated at a 3°C/min heating rate from 20 to 85°C with 0.5% strain and 1.0 Hz frequency. G', G'', and tan δ were measured in duplicate.

### Volatile Compounds

The method for analyzing volatile compounds was adapted from Hayaloglu and Karabulut (2013). To prevent volatile components evaporation, LFCC samples were vacuum packaged, and air shipped to the National University of Singapore where they were stored at −20°C upon arrival. Before analysis, the samples were sliced into 2.5–5.1 cm³ cubes, and the sample was transferred to 20-mL solid phase microextraction (SPME) vial. An internal standard consisting of 2 µL of 1000 ppm 2-methyl, 3-heptanone in ethanol was added to each vial before quantitative analysis using gas chromatography (Agilent 6890A) coupled with mass spectrometry (Agilent 5975C, Triple-Axis detector) and flame ionization detection (Agilent, Santa Clara, CA, USA) on a CTC Combi-PAL autosampler (CTC Analytics, Zwingen, CH). Samples were pre-incubated for 2 min at 40°C before extraction at 40°C for 30 min using a Carboxen/Polydimethylsiloxane (CAR/PDMS) SPME fiber (Supelco, Bellefonte, PA, USA) at 250 rpm/min. The fiber was desorbed in the inlet for 2 min at 250°C using splitless mode, and the carrier gas used was helium with a flow rate of 1.2 mL/min. Separation was achieved using Agilent nitrotetraphthalic-acid-modified polyethylene glycol (DB-FFAP) column (60 m × 0.25 mm × 0.25 µm; Santa Clara, CA, USA). The GC oven temperature program consisted of a 5-min hold at 50°C, followed by an increase to 240°C at a rate of 5°C/min, and a 5-min holding at 240°C. Identification of volatile compounds was based on mass spectra compared with the NIST14 mass spectral library and linear retention index. Volatiles were quantified (expressed as µg/g of cheese) by comparing the peak area of the internal standard and an unknown compound (and respective concentration).

### Statistical Analysis

Statistical analysis was performed by using Minitab 20.0 software (Minitab Inc., State College, PA, USA). The influence of cheese type on each parameter at the same storage time was investigated by using the one-way ANOVA test. To investigate the impact of storage period in the different parameters, one-way ANOVA was performed on the same cheese type (P < 0.05). The comparison between the mean values for the same cheese type or at the same ripening time was carried out by using Tukey’s test (P < 0.05).

### RESULTS

#### Chemical Composition and pH Value

The chemical composition of LFCC treatments after 14 d of ripening is shown in Table 1. There were no significant differences (P > 0.05) in the chemical composition between cheese samples, except for salt content and salt-in-moisture, which were significantly (P < 0.05) lower in sample BM than in CM15 and CM30 (Table 1). The pH value was monitored during the ripening period (Table 1), and no significant (P > 0.05) differences were observed in the pH values of LFCC samples throughout the storage period. It was also shown that the pH of all cheese samples slightly
declined during storage from 5.2 at d 60 to 4.9–5.0 at d 180. Similar results were reported by Amelia et al. (2013).

**Proteolysis Assessment**

Figure 1 shows the analysis of WSN and TCA-SN contents in LFCC samples. The results indicate that LFCC made from BM only exhibited significantly ($P < 0.05$) lower WSN contents than LFCC made from BM-CM blends at all time points, with no significant differences between CM15 and CM30 (Figure 1A). WSN increased in all LFCC samples during ripening. Regarding the TCA-SN content (Figure 1B), it was shown that CM15 had the lowest TCA-SN content (4.7%) at d 60, with no significant differences from other samples. On the other hand, there were significant ($P < 0.05$) differences in TCA-SN content at d 120 representing 5.7%, 7.5%, and 8.4% for BM, CM15, and CM30 treatments, respectively. Similarly, LFCC samples showed significant ($P < 0.05$) differences in their content of TCA-SN after 180 d of ripening making up 6.9%, 8.6%, and 14.0% for BM, CM15%, and CM30%, respectively.

Figure 2 shows the SDS-PAGE results of LFCC pellets obtained after preparing the pH 4.6-WSE of cheese samples at 60, 120, and 180 d of ripening. During the aging process, protein degradation was observed, which was demonstrated by changes in band intensity over time. Figure 2 reveals that major milk proteins such as β-casein, κ-casein, αs1-casein, and αs2-casein were partially or fully hydrolyzed. The intensity of casein bands strongly decreased as time progressed. β-CN and αs1-CN were clearly hydrolyzed during the storage period. A study by Ivens et al. (2017) showed similar findings of proteolysis in aging Cheddar cheese. In LFCC made with camel milk, the intensity of the β-CN band was observed to be higher than the control (BM only) (Figure 2). With storage prolonged, the intensity of

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ripening time (day)</th>
<th>BM</th>
<th>CM15</th>
<th>CM30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture (g/100g)</td>
<td>14</td>
<td>41.8 ± 0.4*</td>
<td>42.3 ± 0.3*</td>
<td>43.8 ± 0.6*</td>
</tr>
<tr>
<td>Fat (g/100g)</td>
<td>14</td>
<td>13.5 ± 1.4*</td>
<td>12.9 ± 1.0*</td>
<td>13.1 ± 1.3*</td>
</tr>
<tr>
<td>FDM (g/100g)</td>
<td>14</td>
<td>23.2 ± 1.3*</td>
<td>22.4 ± 1.0*</td>
<td>23.3 ± 1.2*</td>
</tr>
<tr>
<td>Protein (g/100g)</td>
<td>14</td>
<td>32.2 ± 0.54*</td>
<td>30.6 ± 1.0*</td>
<td>29.9 ± 0.6*</td>
</tr>
<tr>
<td>Salt (g/100g)</td>
<td>14</td>
<td>1.9 ± 0.02b</td>
<td>2.1 ± 0.0*</td>
<td>2.4 ± 0.1*</td>
</tr>
<tr>
<td>MNFS (g/100g)</td>
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<td>48.6 ± 0.3*</td>
<td>50.3 ± 0.7*</td>
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<tr>
<td>S/M (g/100g)</td>
<td>14</td>
<td>4.6 ± 0.1*</td>
<td>4.9 ± 0.0*</td>
<td>5.4 ± 0.0*</td>
</tr>
<tr>
<td>Ash (g/100g)</td>
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<td>4.2 ± 0.1*</td>
<td>4.0 ± 0.1*</td>
<td>3.9 ± 0.1*</td>
</tr>
<tr>
<td>pH</td>
<td>60</td>
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<td>5.2 ± 0.0*</td>
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</tr>
<tr>
<td></td>
<td>120</td>
<td>5.1 ± 0.0*</td>
<td>5.1 ± 0.1*</td>
<td>5.1 ± 0.0*</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>4.9 ± 0.1*</td>
<td>5.1 ± 0.0*</td>
<td>5.0 ± 0.1*</td>
</tr>
</tbody>
</table>

Values are the mean ± standard deviations (n = 3).

*ab Mean values in the same row with different lowercase letters differ significantly ($P < 0.05$).

MNFS, moisture in the nonfat substances; FDM, fat in dry matter; S/M, salt in moisture.
residues migrating below the 25-kDa molecular weight marker increases, indicating a rise in the presence of molecular-weight peptides.

Melting properties

The meltability and oiling-off properties of LFCC during ripening period are presented in Figure 3. At d 60, no significant differences (P > 0.05) in meltability were observed between samples (Figure 3A). The meltability of all cheese samples significantly (P < 0.05) increased after 120 d of ripening, and BM sample had a significantly (P < 0.05) lower meltability (39.6%) than that of CM15 (64.8%) and CM30 (70.1%). After 180 d of ripening, comparable values and differences between samples as those observed at d 120 were observed (Figure 3A). The oiling off in LFCC samples is shown in Figure 3B. Cheese sample prepared from BM displayed significantly (P < 0.05) lower oiling off values (9.6, 25.0, and 24.6% at d 60, 120, and 180) compared with the CM15 and CM30 samples, between which no significant (P > 0.05) differences were observed at any ripening time.

The color parameters L*, a*, and b* values of melted LFCC samples during ripening are presented in Table 2. The cheese prepared from BM only displayed significantly (P < 0.05) higher L* values throughout the 180 d of ripening. Additionally, the CM30 treatment exhibited lower L* values compared with the CM15 treatment at 60, 120, and 180 d of ripening. With respect to the a* values of the LFCC samples, the results indicated that cheese samples made from BM only showed significantly (P < 0.05) lower a* values as compared with those made from BM-CM blends at d 60 and 180. In addition, it was shown that CM30 treatment had significantly (P < 0.05) higher a* values compared with the CM15 treatment throughout ripening period. It was also observed that the CM30 samples exhibited significantly (P < 0.05) higher b* values than BM and CM15 samples.

Cheese Microstructure

The microstructural characteristics of LFCC, determined by SEM at 60, 120, and 180 d of ripening, are presented in Figure 4. The obtained micrographs show clear variations in the microstructure of LFCC made from BM only or blends of BM and CM. On d 60, the BM cheese exhibited a rough granular surface, whereas CM15 and CM30 had a smooth surface. On d 120, the BM and CM15 treatments showed a thick network of aggregated caseins and narrower holes, however, holes were absent in the microstructure of the CM30. Additionally, CM15 and CM30 exhibited granular aggre-
The results revealed that at 180 d of ripening, CM15 and CM30 had a smooth surface, while the BM cheese exhibited a slightly rough structure with a granular surface.

### Texture Profile Analysis

Table 3 presents the texture profile analysis of LFCC samples at 60, 120, and 180 d of ripening. On d 60, LFCC made from BM (4.7 Kg) and CM15 (4.8 Kg) had comparable hardness but significantly ($P < 0.05$) higher than CM30 (2.4 Kg) cheese. The hardness of all cheese samples significantly ($P < 0.05$) decreased throughout storage. In addition, CM30 had significantly ($P < 0.05$) higher cohesiveness (1.7) as compared with BM and CM15 cheese samples on d 60. At 180 d, the highest cohesiveness (1.1) was recorded for the CM15 treatment. The results indicated that there were no significant ($P > 0.05$) differences in the adhesiveness of LFCC samples, and the adhesiveness of the cheese made from BM only remained constant (0.1 mJ) during ripening period. Furthermore, CM15 treatment showed higher adhesiveness (0.4 mJ) as compared BM and CM30 samples. Moreover, LFCC prepared from BM exhibited higher gumminess than CM13 and CM30 at 60, 120, and 180 d. Significant ($P < 0.05$) differences in the gumminess of the LFCC samples were observed at 180 d. Additionally, BM cheese samples had higher chewiness than the CM15 and CM30 treatments. There were significant ($P < 0.05$) differences in the chewiness of LFCC samples at 120 and 180 d of ripening, representing 3.7, 2.4, and 1.6 kg at 120 d and 3.1, 2.4, and 1.4 kg at 180 d for BM, CM15, and CM30 treatments, respectively.

### Rheological Properties

Figure 5A-F presents the frequency sweep tests conducted on LFCC samples. The results show that for all cheese samples, $G'$ was higher than $G''$ indicating a gel-like or solid structure. Both $G'$ and $G''$ moduli increased with the increase in the applied frequency from
0.5 to 16 Hz. At d 60, the G’ of LFCC made from BM only was higher than that of cheese samples CM15 and CM30. At d 120, the LFCC samples displayed comparable G’ and G” values. However, noticeable variations in the G’ values of cheese samples were observed at d 180, while the G” values remained relatively comparable. Moreover, both G’ and G” in all LFCC samples were higher at d 180 compared with d 60. The results in Figure 5G-I reveal that tan δ was ≤1 in all cheese samples, with CM30 treatment exhibiting higher values than BM and CM15 at 60 d of storage. At d 120, tan δ gradually increased, and CM15 treatment showed the highest value. As the storage period progressed to 180 d, tan δ increased to around 1, with the highest value observed for CM15, followed by CM30 and then BM.

Temperature sweeps are commonly used to study material structures. The obtained data show that increasing the temperature from 25 to 85°C caused a decrease in G’, G”, and an increase in tan δ (a decrease in G’ indicates softening of the cheese), except for the samples stored for 60 d, where G’ and G” slightly increased with temperature (Figure 6). The increase in G’ indicates a hardening of the cheese. Table 4 shows the data extracted from the temperature sweep test for LFCC samples during ripening. The melting temperature (T_m) is the temperature at the crossover point G’

Figure 4. Scanning electron microscopy images of low-fat Cheddar cheese (LFCC) made from bovine milk (BM) or BM blended with 15% camel milk (CM15) or 30% (CM30) during storage for 60, 120, and 180 d.
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Table 3. Texture profile analysis of low-fat cheddar cheese (LFCC) made from bovine milk (BM) or BM blended with 15% camel milk (CM15) or 30% (CM30) at d 60, 120 and 180

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Ripening time (day)</th>
<th>BM</th>
<th>CM15</th>
<th>CM30</th>
</tr>
</thead>
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<tr>
<td>Hardness (kg)</td>
<td>60</td>
<td>4.7 ± 0.46(\text{Ab})</td>
<td>4.8 ± 0.38(\text{Aa})</td>
<td>2.4 ± 0.33(\text{Bb})</td>
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<tr>
<td></td>
<td>120</td>
<td>3.5 ± 0.20(\text{Bb})</td>
<td>4.5 ± 0.61(\text{Aa})</td>
<td>2.1 ± 0.41(\text{Bb})</td>
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<tr>
<td></td>
<td>180</td>
<td>3.4 ± 0.34(\text{Bb})</td>
<td>2.6 ± 0.28(\text{Bb})</td>
<td>1.9 ± 0.23(\text{Bb})</td>
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<tr>
<td>Cohesiveness</td>
<td>60</td>
<td>0.8 ± 0.01(\text{Bb})</td>
<td>0.8 ± 0.01(\text{Bb})</td>
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<tr>
<td></td>
<td>120</td>
<td>0.9 ± 0.01(\text{Aa})</td>
<td>0.9 ± 0.01(\text{Aa})</td>
<td>0.8 ± 0.01(\text{Bb})</td>
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<td></td>
<td>180</td>
<td>1.0 ± 0.13(\text{Bb})</td>
<td>1.1 ± 0.23(\text{Bb})</td>
<td>0.8 ± 0.01(\text{Bb})</td>
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<tr>
<td>Adhesiveness (mJ)</td>
<td>60</td>
<td>0.1 ± 0.04(\text{Bb})</td>
<td>0.4 ± 0.33(\text{Aa})</td>
<td>0.1 ± 0.09(\text{Aa})</td>
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<td></td>
<td>120</td>
<td>0.1 ± 0.06(\text{Aa})</td>
<td>0.1 ± 0.07(\text{Bb})</td>
<td>0.1 ± 0.10(\text{Bb})</td>
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<td>180</td>
<td>0.1 ± 0.12(\text{Bb})</td>
<td>0.2 ± 0.23(\text{Bb})</td>
<td>0.2 ± 0.14(\text{Bb})</td>
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<tr>
<td>Springiness index</td>
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<td>0.88 ± 0.02(\text{Aa})</td>
<td>0.85 ± 0.03(\text{Aa})</td>
<td>0.87 ± 0.03(\text{Aa})</td>
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<tr>
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<td>120</td>
<td>0.89 ± 0.01(\text{Aa})</td>
<td>0.90 ± 0.01(\text{Aa})</td>
<td>0.88 ± 0.02(\text{Aa})</td>
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<td>180</td>
<td>0.88 ± 0.01(\text{Aa})</td>
<td>0.87 ± 0.02(\text{Aa})</td>
<td>0.85 ± 0.01(\text{Aa})</td>
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<tr>
<td>Gumminess (kg)</td>
<td>60</td>
<td>4.0 ± 0.37(\text{Aa})</td>
<td>3.9 ± 0.27(\text{Aa})</td>
<td>3.9 ± 0.11(\text{Aa})</td>
</tr>
<tr>
<td></td>
<td>120</td>
<td>3.0 ± 0.16(\text{Bb})</td>
<td>3.8 ± 0.50(\text{Bb})</td>
<td>1.8 ± 0.33(\text{Bb})</td>
</tr>
<tr>
<td></td>
<td>180</td>
<td>3.5 ± 0.22(\text{Bb})</td>
<td>2.8 ± 0.30(\text{Bb})</td>
<td>1.6 ± 0.19(\text{Bb})</td>
</tr>
<tr>
<td>Chewiness (kg)</td>
<td>60</td>
<td>3.5 ± 0.53(\text{Bb})</td>
<td>3.3 ± 0.15(\text{Bb})</td>
<td>3.4 ± 0.09(\text{Bb})</td>
</tr>
<tr>
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<td>120</td>
<td>3.7 ± 0.15(\text{Bb})</td>
<td>2.4 ± 0.42(\text{Bb})</td>
<td>1.6 ± 0.26(\text{Bb})</td>
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<tr>
<td></td>
<td>180</td>
<td>3.1 ± 0.17(\text{Bb})</td>
<td>2.4 ± 0.21(\text{Bb})</td>
<td>1.4 ± 0.13(\text{Bb})</td>
</tr>
</tbody>
</table>

Values are the mean ± standard deviations (n = 6).
\(\text{A-C}\) Mean values in one row with different uppercase letters differ significantly \((P < 0.05)\).
\(\text{a-b}\) Mean values in one column for the same textural parameter with different lowercase letters differ significantly \((P < 0.05)\).

\(= G'' \) (tan \(\delta = 1\)). No crossover point was detected in the investigated temperature range \((25–85^\text{C})\) at d 60, meaning that all samples at d 60 did not exhibit the characteristics of a flowable melt because \(G'\) was higher than \(G''\). The temperature at \(\tan \delta = 1\) for d 120 and d 180 was independent of storage time, while \(\tan \delta \text{ max}\) increased with increasing storage time for all LFCC samples. The higher \(\tan \delta \text{ max}\) is related to higher meltability, and the temperature at the \(\tan \delta \text{ max}\) increased with storage time. For d 60, the temperature at the \(\tan \delta \text{ max}\) was the highest for BM and lowest for CM30, while for d 120 and d 180, the temperature at \(\tan \delta = 1\) was similar for BM and CM30 and lower than that of CM15.

Volatile Compounds

Table 5 presents selected volatile compounds (µg/g) in LFCC samples at 180 d of ripening. Among the ketonic compounds, there were no significant differences in the contents of 2-pentanone and 2-heptanone among cheese samples. However, CM15 showed a significantly \((P < 0.05)\) higher content of acetoin (48.54 µg/g) compared with BM (14.56 µg/g) and CM30 (6.23 µg/g) treatments. In addition, LFCC made from BM only exhibited a higher content of aldehyde compounds, represented by hexanal at 10.23 µg/g compared with 8.35 and 7.62 µg/g in CM15 and CM30, respectively. The CM15 sample also showed significantly \((P < 0.05)\) higher amounts of acetic acid, butanoic acid, and hexanoic acid, at 143.74, 160.27, and 50.16 µg/g, respectively, compared with BM and CM30 treatments. Overall, significant \((P < 0.05)\) differences in the total volatile compounds of LFCC were observed at d 180, with the highest content recorded for CM15 (447.78 µg/g), followed by BM (348.61 µg/g) and CM30 (227.24 µg/g).

DISCUSSION

This study investigated how mixing CM and BM affects the characteristics of Cheddar cheese. The slight decrease in pH during ripening (Table 1) is attributed to starter culture activity in cheese (Ayyash et al., 2021). At initial ripening stages, a typical decline in the pH is anticipated to take place owing to the formation of lactic acid through residual lactose metabolism, after that the pH might increase depending on the cheese variety (Sert, Akin and Aktumsek, 2014). In addition, it was reported that the production of alkaline compounds was another factor for the slight increase in the pH at the end of cheese ripening (Özer and Kesenaş, 2019). Attia, Kherouatou and Dhouib (2001) reported that the smaller decline in pH values of cheeses made from camel and bovine milk blends was due to the greater buffering capacity of CM and its slower acidification during fermentation.

With the progression of cheese ripening, caseins and polypeptides undergo hydrolysis to form smaller pep...
Figure 5. Viscoelastic properties (frequency sweep) of low-fat Cheddar cheese (LFCC) during storage for 180 d at 8°C. Blue, BM; red, CM15; green, CM30. BM: bovine milk only; CM15: camel milk added with 15%; CM30: camel milk added with 30%. D60 (A, D, G); D120 (B, E, H); D180 (C, F, I). $G'$ (A, B, C); $G''$ (D, E, F); tan $\delta$ (G, H, I).
tides (McSweeney, 2017). The significantly higher levels of WSN (Figure 1A) observed in mature LFCC prepared from BM-CM blends could be attributed to the primary hydrolysis of milk proteins by residual chymosin (Ardö et al., 2017), as well as the activity of plasmin on casein. It was suggested that CM proteins may be more susceptible to proteolytic breakdown compared with BM proteins (Abdalla et al., 2022a). As lower and intermediate molecular weight peptides are released during ripening, the variations in the TCA-SN content (Figure 1B) of cheese increase (Hayaloglu, Karatekin and Gurkan, 2014). It was reported that several coagulant enzymes result in significant variations in WSN

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Ripening time (day)</th>
<th>LFCC</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BM</td>
<td>CM15</td>
</tr>
<tr>
<td>Tan (δmax)</td>
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<td></td>
<td>180</td>
<td>52.79</td>
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</table>

Values are the mean ± standard deviations (n = 4).

Mean values in the same column, at the same ripening day, with the same lowercase letters differ insignificantly (P > 0.05).

Table 4. Temperature sweep results of low-fat cheddar cheese (LFCC) made from bovine milk (BM) or BM blended with 15% camel milk (CM15) or 30% (CM30) at d 60, 120 and 180

Figure 6. Thermal properties (temperature sweep) of low-fat Cheddar cheese (LFCC) during storage for 180 d at 8°C. Blue: BM, red: CM15, green: CM30. BM: bovine milk only; CM15: camel milk added with 15%; CM30: camel milk added with 30%. G’ (A, B, C); G” (D, E, F); δ (G, H, I). D60 (A, D, G); D120 (B, E, H); D180 (C, F, I).
Cheese meltability is considered a critical functional parameter that reflects the extent to which cheese melts when heated (Sözerı Atik and Huppertz, 2023). The higher melting (Figure 3A) and oiling off (Figure 3B) values in LFCC made from blends of BM and CM compared with LFCC made from BM only may be due to the significantly higher level of proteolysis (Figure 2), in these samples compared with BM samples, which is related to their melting ability (McMahon and Oberg, 2017). The larger size of casein micelles and the high content of β-casein may lead to a weak protein network formed by CM caseins during cheese manufacture, which could subsequently enhance the meltability of LFCC prepared from BM-CM blends. Furthermore, colloidal calcium phosphate has been reported to have an important role in the melting properties of cheese, since increasing the content of colloidal calcium phosphate decreases the susceptibility of the cheese protein matrix to undergo structural rearrangement, accordingly hindering cheese melting and flowability (O'Mahony, McSweeney and Lucey, 2006). Oiling off refers to the tendency of free oil to separate from melted cheese (Ah and Tagalpallewar, 2006). Oiling off reduces the susceptibility of the cheese protein matrix to undergo structural rearrangement, accordingly hindering cheese melting and flowability (O'Mahony, McCarron and Lucey, 2006). The use of CM in LFCC production has been found to affect the microstructure characteristics (Figure 4) of cheese samples during ripening, possibly due to the different physicochemical characteristics of CM. Similar findings were reported by Abdalla et al. (2022a) who found that blending BM and CM affected the microstructure of low-fat Akawi cheese. Milk types with smaller casein micelles, such as BM, have been shown to produce a more compact curd and a firmer gel network compared with milk species with larger micelles, such as CM (Li and Zhao, 2019). Therefore, the larger CM micelles are likely to disrupt the stability of the BM para-casein network, resulting in weak points in the gel matrix and decreased firmness. Additionally, the fewer rearrangements of protein in the gel network may be attributed to the variations in the size of casein micelles, which are about 100–140 nm in BM compared with 260–300 nm in CM (Hailu et al., 2016), resulting in cheese with high moisture content and decreased firmness (Lucey, Johnson and Horne, 2003). Our results indicate that the use of CM significantly influenced the texture characteristics of LFCC prepared from BM-CM blends (Table 3). However, the mechanism of how CM and BM micelles interact and combine to create a cohesive matrix requires further investigation.

The inclusion of CM in cheese milk caused a decrease in the G' and G'' values of the resultant LFCC (Figure 5A and 5D). When G' > G'', the sample will act more like a solid and the deformations will be basically recoverable or elastic, and when G' is lower than G'', the energy required for sample deformation is viscously dissipated, and the materials behave as liquid-like (Tabil-Munizaga and Barbosa-Canovas, 2005). Furthermore,
the large size of casein micelles, the high content of β-casein, and the low content of κ-casein in CM might impair the protein network in CM15 and CM30 treatments (Hailu et al., 2016).

In addition, the melting profile is usually affected by the conditions that affect the protein-protein interactions in the protein matrix and enhance the interactions between water and proteins (McMahon and Oberg, 2017). The protein network in cheese was impaired by using CM, and thus altering the transition temperature (Figure 6). The variations in tan δ values may be attributed to the modified casein interactions in LFCC made from BM-CM blends (Figure 6), which could disturb the regular equilibrium responsible for melting. The weaker protein network in CM15 and CM30 may be responsible for this. The formation of the weak gel in CM has been widely investigated (Boukria et al., 2020, Mbye et al., 2020). The volatile compounds detected in this study (Table 5) have been previously identified in Cheddar cheese by Hannon et al. (2007). The observed differences in the volatile compounds of LFCC at 180 d of ripening may be due to variations in the composition of BM and CM as well as the activity of the starter cultures.

CONCLUSIONS

The present study evaluated the impact of BM blended with CM at 2 levels (15 and 30%) on the characteristics of LFCC during ripening for 180 d. LFCC made from BM only displayed higher L* values, during storage time. Furthermore, the CM30 sample exhibited lower hardness compared with BM and CM15 treatments. Using CM affected the microstructure characteristics, meltability, and oiling off in LFCC. Cheese samples prepared from BM alone exhibited lower meltability and oiling off throughout the ripening period. In all cheese samples, G' was higher than G" indicating that cheese samples had a gel-like or a solid structure, with one exception for the BM15 sample at d 180 as G' ≈G" LFCC made from BM blended with 15% of CM exhibited higher levels of the total volatile compounds than BM and CM30 treatments. Further studies are recommended to investigate the mechanism of how CM interacts with BM and influences cheese characteristics.

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Author Contribution A.H. Ali: Writing - Original Draft; B. Abu-Jdayil: Investigation, Writing-Review & Editing; F. Hamed & Gafar Bamigbade: Investigation; A. Kamal-Eldin: Writing-Review & Editing; Shao-Quan Liu: Investigation, Writing-Review & Editing; T. Huppertz: Writing-Review & Editing; M. Ayyash: Conceptualization, Formal analysis, Writing - Original Draft, Resources, Data Curation, Writing-Review & Editing, Visualization, Supervision, Project administration, Funding acquisition.

Conflict of interests The authors declare no conflict of interest.

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