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# Comparison of camel, buffalo, cow, goat, and sheep yoghurts in terms of various physicochemical, biochemical, textural and rheological properties

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ABSTRACT

Comparative physicochemical, biochemical, textural, and rheological properties of yoghurts produced using buffalo, camel, cow, goat, and sheep milk were analysed. The physicochemical, textural, and rheological properties were determined over a 14-day storage period. Different animal milk types had a significant effect on all physicochemical analyses, fatty acid composition, conjugated linoleic acid content, cholesterol content, all amino acids except asparagine, ACE inhibitory activity, citric acid, and orotic acid, as well as other textural and rheological properties, except flow index n parameter. The storage period had a very significant effect on titratable acidity, pH value, firmness, consistency, cohesiveness, and yield stress τ0 parameters. Compared with other yoghurts studied, camel yoghurt was richer in terms of myristic acid from saturated fatty acids, ∑PUFA, arginine, lysine, phenylalanine, tryptophan, valine from essential amino acids, glutamic acid, and proline from non-essential amino acids, ACE inhibitory activity value, and hippuric and orotic acids.

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## 1. Introduction

Cardiovascular diseases are one of the main causes of death worldwide and are reported to be associated with high blood pressure and serum cholesterol. Today, various side effects of drugs used in the treatment of cardiovascular diseases have brought the search for natural resources to the agenda, and in this context, functional foods have also attracted attention (Kumar et al., 2022). Milk and dairy products exhibit functional food characteristics due to the unique components they contain such as fatty acids, amino acids, vitamins, and mineral substances. Various bioactive compounds that are beneficial for health are formed by the use of lactic acid bacteria in the production of dairy products. Bioactive peptides formed during the production of fermented milk products such as yoghurt show angiotensin-converting enzyme (ACE) inhibitory activity properties that drugs have used in the treatment of hypertension (Rai, Sanjukta, & Jeyaram, 2017). It is also reported that yoghurt contributes to the reduction of cholesterol levels by means of its protein, conjugated linoleic acid, and mineral substance contents (Kumar et al., 2022).

Although cow milk is widely used (83%) in the production of drinking milk or dairy products, the use of other types of milk has come to the fore in this field due to the fact that consumers are more conscious and functional foods are gaining popularity. In the

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production of dairy products, compared with cow milk, it has been reported that the use of camel milk is superior in terms of essential fatty acids, vitamins, and mineral substances, the use of buffalo milk is superior in terms of lactose, protein, vitamins and mineral substances (Galeboe, Seifu, & Sekwati-Monang, 2018), the use of sheep milk is superior in terms of protein, essential amino acids, fat and short-chain fatty acids, and the use of goat milk is superior in terms of protein, fat, medium-chain fatty acids and vitamins (Boukria et al., 2020). For these reasons, scientific studies in recent years have focused on the use of buffalo, camel, goat, and sheep milk instead of cow milk in fermented milk products such as yoghurt and the improvement of their functional properties.

Although some studies have been carried out to date (El Zubeir, Basher, Alameen, Mohammed, & Shuiep, 2012; Moschopoulou et al., 2018; Wang et al., 2023), to the best of our knowledge, there is no study that investigates and compares various physicochemical, biochemical (fatty acid composition, cholesterol content, amino acid profile, ACE inhibitory activity, and organic acid profile), textural, and rheological properties of yoghurts produced with camel milk and yoghurts produced with buffalo, cow, goat and sheep milk at the same time. Although different animal milk types have relatively similar compositions, each has its own superior characteristics. In this context, it is important to get information about the organic acid profile, which is important in the characteristic aroma of yoghurt, amino acid profile, fatty acid composition and CLA content, which is important in nutritional value, ACE inhibitory activity, which is important in nutraceutical properties, textural and rheological properties, which are important in consumer preference.

Therefore, in the current research, the fatty acid composition, conjugated linoleic acid content, cholesterol content, amino acid profile, ACE inhibitory activity value, organic acid profile, textural, and rheological properties of yoghurts produced using different types of milk (buffalo, camel, cow, goat, and sheep) and classical yoghurt culture (*Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*) were determined and compared with each other. In addition to their pharmaceutical and/or therapeutic utility, the textural properties of these yoghurts were also investigated. In addition, various quality criteria (total solids, fat, protein, ash, titratable acidity, and pH values) were also determined during the storage period of the yoghurts.

## 2. Materials and methods

### 2.1. Milk, milk powder and starters

Camel milk used as raw material in the present study was obtained from local farms in Denizli (Türkiye), while buffalo, cow, goat, and sheep milk were obtained from local farms in Erzurum (Türkiye). The classical yoghurt culture (YC-350-*L. delbrueckii* subsp. *bulgaricus* and *S. thermophilus*) used in yoghurt production was supplied through CHR Hansen (Süt-Sa Süt Sanayii Adapazarı/Türkiye). Skimmed cow milk powder was obtained from the Bağdat Baharat company from Ankara (Türkiye) and the average total solids content of it was determined as 95.34%, fat content as 1.19%, protein content as 35.51%, ash content as 8.22%, titratable acidity value as 0.15% LA and pH value as 6.81 (10% solution) (Terzioğlu, 2022).

### 2.2. Experimental yoghurt production

Pre-treatment (purification and homogenisation) was applied to the milk of different animal species used in the production of experimental yoghurt and 3% skimmed milk powder was added. Then, the milk was taken separately to the pasteurisation tank and subjected to heat treatment at 90 °C for 10–15 min. Then, classical yoghurt culture (*L. delbrueckii* subsp. *bulgaricus* and *S. thermophilus*) was added at the appropriate temperature and rate (43–45 °C and 20 g 100 $L^{-1}$) on the basis of direct vat inoculation and incubated in 200 mL glass jars. Yoghurt samples, which were incubated (43–45 °C) in the incubators (Memmert, UN55) until the pH value reached 4.6 ± 0.1, were stored at 4 °C to be used in the analyses.

Physicochemical, textural, and rheology analyses of the yoghurt samples were performed on days 1, 7 and 14 of storage, while all other analyses were performed on day 1 of storage.

### 2.3. Physicochemical analyses of raw milk and yoghurt samples

Total solids, fat, protein, ash, titratable acidity, and pH values of raw milk used as raw material and experimental yoghurt samples were performed with reference to Terzioğlu and Bakırcı (2023) and Terzioğlu, Yıldız Küçük, and Bakırcı (2022).

### 2.4. Determination of fatty acid composition and conjugated linoleic acid content (CLA)

Gas chromatography (GC, QP2010, Shimadzu, Kyoto, Japan) was used to determine the fatty acid composition and CLA content of the experimental yoghurt samples, and the method given by Satchithanandam, Fritsche, and Rader (2001) was taken as a basis. Fatty acid composition and CLA analysis were performed using a Restek RTX-2330 capillary column (60 m × 0.25 mm × 0.1 μm) and a flame ionisation detector (FID, QP2010) in gas chromatography. In GC-FID, the column furnace temperature was set to 240 °C and the injector and detector temperature were set to 250 °C. Helium (1 mL $min^{-1}$) was used as the carrier gas in the system.

The identification of the analyte peaks was established by comparing retention times of the analyte peaks in the samples with retention times of the mix standard (Supelco, CRM47885). For the quantification, area calculation of the analyte peaks in the samples was done according to those of standard solutions.

### 2.5. Determination of cholesterol content

For the cholesterol content analysis of the experimental yoghurt samples, methanolic potassium hydroxide (KOH) solution was added to the yoghurt samples and kept in a water bath at 80 °C for 15 min. Centrifugation was carried out by adding 5 mL of n-hexane and 1 mL of distilled water to the samples cooled to room temperature. Then, 1 mL of the upper phase was taken and a reading was made in gas chromatography-flame ionisation detector (GC-FID, QP2010, Shimadzu, Kyoto, Japan). In GC-FID, the column oven temperature was 285 °C and the injection and detector temperature was 300 °C. Helium as a carrier gas in the system was adjusted to a flow rate of 2 mL $min^{-1}$. The identification and quantification of cholesterol was determined according to the retention time and peak area of the cholesterol standard (Sigma, C8667) and stigmasterol (Sigma, S2424) standard (Fletouris, Botsoglou, Psomas, & Mantis, 1998).

### 2.6. Determination of amino acid profile

For the amino acid profile analysis of the yoghurt samples, the method of Atila et al. (2021) was taken as a reference, and the analyses were carried out by making some modifications to the method. Yoghurt sample (100 μL) was mixed with 50 μL of internal standard and 650 μL of amino acid solvent (mobile phase A, mobile phase B, 1/4, v/v) and subjected to centrifugation (10,000 × *g*, 8 min). Quantitative values were obtained by relating chromatographic peak areas to those derived from externally run calibration

standards and using the institutional database. The amino acid profile was determined using the liquid chromatography-tandem mass/mass spectrometer system (LC–MS/MS, Agilent 6460 Triple Quadropol, USA) and the details of the LC–MS/MS analysis conditions are given in theSupplementary material Table S1.

### 2.7. Determination of ACE inhibitory activity

The method applied by Cushman and Cheung (1971) and Nakamura et al. (1995) was modified to determine the ACE inhibitory activity value of yoghurt samples. Yoghurt sample (50 μL), hippuryl-L-histidyl-L-leucine (HHL, 180 μL) solution, and ACE solution (20 μL) were mixed together. It was then incubated (at 37 °C for 90 min) and the incubation was completed by adding 250 μL of 1 M HCl solution. Ethyl acetate (1.7 mL) was added to the mixture and evaporated (at 100 °C for 15 min). By adding 1 mL of distilled water to the hippuric acid solution formed; the absorbance was measured at a wavelength of 228 nm in a UV-spectrophotometer (Optizen POP) and the ACE inhibitory activity calculated by:

$$\text{ACE inhibitory activity } (\%) = 100 - [100 \times (C - D)/(A - B)]$$

where A is the absorbance in the presence of ACE solution, without yoghurt sample; B is the absorbance without ACE solution and yoghurt sample; C is the absorbance in the presence of ACE solution and yoghurt sample and D is the absorbance of yoghurt sample without ACE solution.

### 2.8. Determination of organic acid profile

In the determination of the organic acid profile (citric acid, hippuric acid, lactic acid, orotic acid, pyruvic acid, tartaric acid, and uric acid) of the yoghurt samples, the method given by Çelik, Gerçek, Özkök, and Ecem Bayram (2022) was taken as a basis and the content was determined by making some changes. For this purpose, 5 g of yoghurt sample was weighed and centrifuged by adding 5 mL of methanol. After centrifugation, 900 μL solvent (0.2% formic acid in distilled water) was added to 100 μL supernatant. The organic acid profile of the yoghurt samples was determined using Agilent Zorbax SB-C8 column (150 mm × 3.0 mm, 3.5 μm particle size, Agilent Technologies) in LC–MS/MS (Agilent 6460 Triple Quadropol, USA) and details of LC–MS/MS analysis conditions are given in theSupplementary material Table S2.

### 2.9. Texture and rheology analyses

The texture analysis (firmness, consistency, and cohesiveness) of the experimental yoghurt samples was carried out by making some modifications to the method given by Boz (2012). In the texture analysis of yoghurt samples, TA.XTplus Texture Analyzer (Stable Micro Systems Ltd., Godalming, UK) device and a probe with a diameter of 40 mm were used. Test speed, pre-test speed, and post-test speed were taken as 3.00 mm $s^{-1}$, distance as 30 mm, and trigger force as 5 g. The rheology analysis (yield stress τ0, consistency k, and flow index) of the experimental yoghurt samples was performed by making some modifications to the method given by Yeung, Lee, and Chang (2019). Rheological analysis of yoghurt samples was performed with Reocompass 1.25 software using a rheometer device (Anton Paar MCR 102, Austria).

### 2.10. Statistical analysis

In the present study, all yoghurt productions and analyses were performed in two replications and two parallel samples were used in each replication. The analyses of the experimental yoghurt samples produced with different milk types (buffalo, camel, cow, goat and sheep) were carried out according to the completely randomised block designs. Statistical analyses were interpreted using the SPSS 20 package program and Duncan multiple comparison test. Principal Component Analysis (PCA) was performed using SIMCA-P + 14.1 (UMETRICS, Umea, Sweden) software.

## 3. Results

### 3.1. Physicochemical analyses

The results of various physicochemical analyses of the milk of buffalo, camel, cow, goat, and sheep, skimmed milk powder, and the experimental yoghurt samples are given in Table 1.

Of the different animal milk types, sheep milk had the highest content of total solids, fat, protein, and ash, while cow milk had the lowest values. The chemical compositions of raw milk of different animal species and skimmed milk powder were in agreement with the data in the literature (Arslaner, Salik, & Bakirci, 2021; Boukria et al., 2020; El-Hanafy et al., 2023).

The use of milk of different animals in yoghurt production had a very significant effect ($P < 0.01$) on all physicochemical analyses (total solids, fat, protein, ash, titratable acidity, and pH values) examined in the current study, while the storage time had a very significant effect ($P < 0.01$) on the titratable acidity and pH values of the yoghurt samples alone. The highest total solids, fat, protein, and ash contents were determined in sheep yoghurt samples, the highest titratable acidity value was determined in cow yoghurt, and the highest pH value was determined in camel yoghurt.

During the storage period (1, 7 and 14 days), it was found that the acidity increased and the pH value decreased in the entire yoghurt samples, as expected, at a very significant level ($P < 0.01$). Balthazar et al. (2016) reported that the pH value of sheep yoghurt varied between 4.37 and 4.52 and the titratable acidity value varied between 1.15 and 1.35% LA. Galeboe et al. (2018) reported that the total solids content of camel yoghurt was 19.45%, the ash content was 0.71%, the pH value was 4.67, and the titratable acidity value was 0.87% LA. Terzioğlu (2022), on the other hand, revealed that the total solids content of cow yoghurt was 15.23%, the fat content was 4.37% and the protein content was 4.20%, while the total solids content of goat yoghurt was 16.38%, the fat content was 4.83% and protein content was 4.74%.

It is reported that the fact that skim milk powder is rich in protein and lactose makes positive contributions on various physicochemical and sensory properties of yoghurt. In addition, milk powders from different animal milk types have been reported to affect the protein content, amino acid profile, consistency, viscosity and serum separation value of the yoghurt (González-Martínez et al., 2002; Salih & Hamid, 2013; Wang et al., 2023).

### 3.2. Fatty acid composition, CLA, and cholesterol content results

Fatty acid composition, CLA, and cholesterol content results of the buffalo, camel, cow, goat, and sheep yoghurt samples are shown in Table 2.

The use of different animal milk types in yoghurt production had a very significant effect ($P < 0.01$) on all fatty acids, CLA, and cholesterol content. It was determined that the dominant fatty acids in yoghurt samples produced from different animal milk types were myristic, palmitic, stearic acid, oleic, and linoleic acids. The higher content of saturated fatty acids (SFA) compared with unsaturated fatty acids (USFA) in animal-derived fats is a health concern (Mantzourani, Batsika, Kokotou, & Kokotos, 2022). The highest ∑SFA content was determined in sheep yoghurt, while the lowest ∑SFA content was determined in cow yoghurt. When the

**Table 1**
The physicochemical analysis results of the different animals' milk and the experimental yoghurt samples.[a]

| Parameter | Total solids (%) | Fat (%) | Protein (%) | Ash (%) | Titratable acidity (lactic acid, %) | pH |
|---|---|---|---|---|---|---|
| Milk type | | | | | | |
| Buffalo | 17.34 ± 0.05$^{b}$ | 7.47 ± 0.04$^{b}$ | 4.08 ± 0.01$^{b}$ | 0.83 ± 0.01$^{b}$ | 0.21 ± 0.01$^{a}$ | 6.64 ± 0.02$^{a}$ |
| Camel | 13.55 ± 0.03$^{c}$ | 4.63 ± 0.01$^{c}$ | 3.54 ± 0.01$^{d}$ | 0.72 ± 0.02$^{c}$ | 0.20 ± 0.01$^{a}$ | 6.68 ± 0.04$^{a}$ |
| Cow | 12.67 ± 0.04$^{e}$ | 3.76 ± 0.01$^{e}$ | 3.40 ± 0.02$^{e}$ | 0.71 ± 0.01$^{c}$ | 0.20 ± 0.00$^{a}$ | 6.66 ± 0.01$^{a}$ |
| Goat | 13.14 ± 0.02$^{d}$ | 3.92 ± 0.03$^{d}$ | 3.71 ± 0.01$^{c}$ | 0.82 ± 0.03$^{b}$ | 0.19 ± 0.00$^{a}$ | 6.73 ± 0.01$^{a}$ |
| Sheep | 19.25 ± 0.01$^{a}$ | 7.88 ± 0.01$^{a}$ | 5.52 ± 0.03$^{a}$ | 0.96 ± 0.04$^{a}$ | 0.21 ± 0.01$^{a}$ | 6.65 ± 0.03$^{a}$ |
| Sig. | ** | ** | ** | ** | ns | ns |
| Yoghurt type | | | | | | |
| Buffalo | 19.52 ± 0.13$^{b}$ | 8.25 ± 0.12$^{b}$ | 5.31 ± 0.05$^{b}$ | 0.93 ± 0.02$^{b}$ | 1.04 ± 0.10$^{c}$ | 4.24 ± 0.10$^{c}$ |
| Camel | 16.25 ± 0.16$^{c}$ | 5.56 ± 0.06$^{c}$ | 4.82 ± 0.02$^{d}$ | 0.82 ± 0.01$^{d}$ | 0.90 ± 0.07$^{e}$ | 4.37 ± 0.08$^{a}$ |
| Cow | 15.25 ± 0.11$^{e}$ | 4.55 ± 0.05$^{e}$ | 4.25 ± 0.03$^{e}$ | 0.82 ± 0.01$^{d}$ | 1.11 ± 0.12$^{a}$ | 4.16 ± 0.12$^{e}$ |
| Goat | 15.59 ± 0.10$^{d}$ | 4.77 ± 0.04$^{d}$ | 5.04 ± 0.03$^{c}$ | 0.87 ± 0.02$^{c}$ | 1.08 ± 0.11$^{b}$ | 4.19 ± 0.11$^{d}$ |
| Sheep | 21.42 ± 0.19$^{a}$ | 9.35 ± 0.01$^{a}$ | 6.11 ± 0.05$^{a}$ | 1.03 ± 0.02$^{a}$ | 0.99 ± 0.09$^{d}$ | 4.30 ± 0.08$^{b}$ |
| Sig. | ** | ** | ** | ** | ** | ** |
| Storage period (days) | | | | | | |
| 1 | 17.61 ± 2.49$^{a}$ | 6.51 ± 2.09$^{a}$ | 5.11 ± 0.65$^{a}$ | 0.90 ± 0.09$^{a}$ | 0.91 ± 0.05$^{c}$ | 4.37 ± 0.06$^{a}$ |
| 7 | 17.62 ± 2.56$^{a}$ | 6.49 ± 2.04$^{a}$ | 5.11 ± 0.67$^{a}$ | 0.89 ± 0.09$^{a}$ | 1.05 ± 0.09$^{b}$ | 4.23 ± 0.09$^{b}$ |
| 14 | 17.58 ± 2.67$^{a}$ | 6.49 ± 2.01$^{a}$ | 5.09 ± 0.62$^{a}$ | 0.89 ± 0.08$^{a}$ | 1.12 ± 0.09$^{a}$ | 4.15 ± 0.09$^{c}$ |
| Sig. | ns | ns | ns | ns | ** | ** |

[a] Different superscript letters in a column indicate significant differences; **, $P < 0.01$; ns, $P > 0.05$; Sig., significance.

**Table 2**
The fatty acid composition (%), CLA (%) and cholesterol (mg 100 $g^{-1}$) contents of experimental yoghurt samples.[a]

| Fatty acid | Yoghurt | | | | | Sig. |
|---|---|---|---|---|---|---|
| | Buffalo | Camel | Cow | Goat | Sheep | |
| Myristic acid (C14:0) | 9.35 ± 0.01$^{e}$ | 12.18 ± 0.02$^{a}$ | 9.83 ± 0.02$^{d}$ | 10.71 ± 0.01$^{c}$ | 11.23 ± 0.04$^{b}$ | ** |
| Palmitic acid (C16:0) | 32.65 ± 0.02$^{a}$ | 23.44 ± 0.01$^{e}$ | 27.13 ± 0.03$^{b}$ | 24.53 ± 0.04$^{d}$ | 24.97 ± 0.01$^{c}$ | ** |
| Stearic acid (C18:0) | 10.47 ± 0.04$^{e}$ | 12.56 ± 0.03$^{c}$ | 13.57 ± 0.01$^{a}$ | 13.08 ± 0.01$^{b}$ | 11.76 ± 0.02$^{d}$ | ** |
| Other SFA | 15.39 ± 0.10 | 15.24 ± 0.08 | 12.21 ± 0.10 | 18.37 ± 0.08 | 21.16 ± 0.09 | – |
| ∑SFA | 67.86 ± 0.04$^{b}$ | 63.42 ± 0.02$^{d}$ | 62.74 ± 0.04$^{e}$ | 66.69 ± 0.03$^{c}$ | 69.12 ± 0.01$^{a}$ | ** |
| Oleic acid (C18:1) | 25.95 ± 0.01$^{b}$ | 16.94 ± 0.04$^{e}$ | 29.46 ± 0.01$^{a}$ | 24.34 ± 0.03$^{c}$ | 20.03 ± 0.01$^{d}$ | ** |
| Other MUFA | 2.95 ± 0.02 | 11.26 ± 0.04 | 4.61 ± 0.00 | 3.81 ± 0.01 | 7.14 ± 0.01 | – |
| ∑MUFA | 28.90 ± 0.04$^{b}$ | 28.20 ± 0.00$^{c}$ | 34.07 ± 0.01$^{a}$ | 28.15 ± 0.02$^{d}$ | 27.17 ± 0.00$^{e}$ | ** |
| Linoleic acid (C18:2) | 2.76 ± 0.04$^{c}$ | 3.26 ± 0.01$^{b}$ | 2.67 ± 0.01$^{c}$ | 3.54 ± 0.06$^{a}$ | 2.37 ± 0.04$^{d}$ | ** |
| Other PUFA | 0.48 ± 0.04 | 5.12 ± 0.01 | 0.52 ± 0.02 | 1.62 ± 0.05 | 1.34 ± 0.02 | – |
| ∑PUFA | 3.24 ± 0.00$^{d}$ | 8.38 ± 0.02$^{a}$ | 3.19 ± 0.04$^{e}$ | 5.16 ± 0.01$^{b}$ | 3.71 ± 0.01$^{c}$ | ** |
| CLA | 0.75 ± 0.01$^{b}$ | 0.82 ± 0.02$^{ab}$ | 0.64 ± 0.05$^{c}$ | 0.86 ± 0.01$^{a}$ | 0.53 ± 0.04$^{d}$ | ** |
| Cholesterol | 15.88 ± 0.01$^{b}$ | 12.95 ± 0.01$^{d}$ | 12.51 ± 0.03$^{e}$ | 14.18 ± 0.06$^{c}$ | 17.09 ± 0.04$^{a}$ | ** |

[a] Abbreviations are: SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; CLA, conjugated linoleic acid; Sig., significance. Different superscript letters in a row indicate significant differences: **, $P < 0.01$.

monounsaturated fatty acid (MUFA) contents were compared, the highest ∑MUFA content was found in cow yoghurt and the lowest ∑MUFA content was determined in sheep yoghurt. When the polyunsaturated fatty acid content (PUFA) of yoghurt samples produced from different types of milk were compared, the highest ∑PUFA content was found in camel yoghurt, while the lowest ∑PUFA content was found in cow yoghurt.

These differences in the fatty acid composition of bovine and ovine milk are explained by differences in milk fat globule diameter and mammary cells, and the type of milk is important, especially since the SFA content is synthesised in the mammary glands of ruminant animals (Karakus, Akgul, Korkmaz, & Atasoy, 2022). However, it is quite difficult to evaluate the fatty acid composition of yoghurts produced from different types of milk. Because it is known that many factors such as the origin of milk, lactation, feeding, season, fermentation, heat treatment, microorganisms, storage, and added additives affect the fatty acid composition of yoghurt (Mantzourani et al., 2022; Paszczyk & Czarnowska-Kujawska, 2022).

In a study conducted for determining the fatty acid composition of different animal milk types by Barłowska, Szwajkowska, Litwińczuk, and Król (2011), it was reported that camel milk had the lowest SFA content (64.86%), the highest MUFA content (33.03%), and the lowest PUFA content (2.12%). On the other hand, the researchers mentioned that cow milk had the highest SFA content (71.24%) and goat milk had the highest PUFA content (4.08%). Therefore, the fact that different animal milk types have different fatty acid compositions is thought to affect the fatty acid composition of the experimental yoghurt samples.

On the other hand, CLA content, which significantly contributes to the functional properties of yoghurt, was determined to be the highest in goat yoghurt (0.86%) ≥ camel yoghurt (0.82%) > buffalo yoghurt (0.75%) > cow yoghurt (0.64%) > sheep yoghurt (0.53%). The CLA content in milk fat is mainly formed by the activity of D9-desaturase in the mammary gland or the biohydrogenation and isomerisation of unsaturated fatty acids by bacteria. Various parameters such as milk type, feeding, season, oxidative reactions, starter culture, fermentation, and heat treatment play a role in the different CLA content in milk types (Serafeimidou, Zlatanos, Kritikos, & Tourianis, 2013). Alichanidis, Moatsou, and Polychroniadou (2016) reported that the average CLA content was 0.8% in sheep milk, 0.7% in cow and goat milk, 0.6% in buffalo milk and 0.4% in camel milk. In this context, in the current research, it was observed that the CLA content of milk, fermentation process

and oxidation reactions had a significant effect on the differences in CLA content of yoghurt samples.

The cholesterol content of the yoghurts produced from different types of milk was determined as 12.51 mg 100 $g^{-1}$ in cow yoghurt, 12.95 mg 100 $g^{-1}$ in camel yoghurt, 14.18 mg 100 $g^{-1}$ in goat yoghurt, 15.88 mg 100 $g^{-1}$ in buffalo yoghurt and 17.09 mg 100 $g^{-1}$ in sheep yoghurt.

Claeys et al. (2014) reported cholesterol content of buffalo, camel, cow, goat and sheep milk as 4–18 mg 100 $mL^{-1}$, 31.3–37.1 mg 100 $mL^{-1}$, 13.1–31.3 mg 100 $mL^{-1}$, 10.7–18.1 mg 100 $mL^{-1}$ and 14–29 mg 100 $mL^{-1}$, respectively. Furthermore, in the current study, the cholesterol content of yoghurts was observed to be linked to SFA contents in addition to milk type.

Although it has been studied for many years, the relationship between dietary cholesterol content and serum cholesterol, and long-chain fatty acids has still not been clearly explained (Soliman, 2018). On the other hand, it has also been reported that 300 mg of cholesterol should be taken daily to use metabolic events such as the synthesis of vitamin D, steroid hormones, and bile acids in the body (Soliman, 2018). However, in recent studies, it has been shown that yoghurt reduces blood cholesterol levels (Ohlsson, 2010; Paszczyk & Czarnowska-Kujawska, 2022). In addition, it has been reported that the inclusion of dairy products in the diet is effective in reducing the risk of cardiovascular diseases by increasing the level of high-density lipoprotein (HDL) cholesterol (Ohlsson, 2010). Furthern, it has been emphasised that fermented products are more effective in lowering plasma cholesterol levels compared with milk (Ohlsson, 2010; Seçkin, Gursoy, Kinik, & Akbulut, 2005). In this context, in the current research, it is seen that sheep yoghurt, which contains the highest cholesterol among yoghurts produced from different animal milk types, exceeds the recommended level of 300 mg only if consumed in very high quantities (about 1800 g), which is not very possible.

### 3.3. Amino acid profile and ACE inhibitory activity

In the current study, the concentrations of 19 amino acids were examined in yoghurt samples produced from different types of milk. The limit of detection (LOD) and limit of quantification (LOQ) values calculated according to the signal/noise ratios are given in theSupplementary material Table S2.

The amino acid profile and ACE inhibitory activities of the buffalo, camel, cow, goat, and sheep yoghurt samples are given in Table 3. It was found that the use of different animal milk types in yoghurt production had a significant effect ($P < 0.05$) on asparagine, while it had a very significant effect ($P < 0.01$) on all other amino acids and ACE inhibitory activity values. When the amino acid profile of yoghurts produced from the milk of different animals was assessed, it was determined that glutamic acid was found to be at the highest level among non-essential amino acids. In yoghurt samples, glutamic acid was followed by proline, while lysine and leucine were found to be the highest among essential amino acids. Lysine, one of the dominant essential amino acids in the amino acid profile, plays a role in growth, bone development, calcium absorption, and nitrogen balance, while leucine is effective in bone development, blood sugar balance, skin, and muscle tissue repair. Glutamic acid, one of the non-essential amino acids, plays a protective role in brain cell activities and cardiovascular diseases, while proline has positive effects on cartilage, joint, and heart muscle (Kavas & Kınık, 2005).

In general, the roles of essential amino acids in important metabolic activities, such as their use as a substrate in gluconeogenesis in addition to their protein synthesis and protein catabolism functions, require their dietary intake (Maduka, Maduka, Ugwu, & Mukthari, 2013). In the current study, when the amino acid profile of camel yoghurt was viewed, it was observed that it showed superior properties compared with other yoghurts in terms of arginine, lysine, phenylalanine, tryptophan and valine from essential amino acids, and glutamic acid, and proline from non-essential amino acids. However, isoleucine, leucine, cystine, and tyrosine in the buffalo yoghurt; histidine, methionine, aspartic acid, and serine in the cow yoghurt; and threonine and alanine in the goat yoghurt were found in higher levels compared with other amino acids.

In addition to the milk type, the cultures used (especially *S. thermophilus*) also have a significant effect on the free amino acid profile in yoghurt. Indeed, *S. thermophilus* metabolically uses glutamic acid, arginine, tryptophan, histidine, tyrosine, leucine, isoleucine, valine, cystine, and methionine amino acids. It is also reported that amino acids such as threonine, isoleucine, leucine, and valine contribute to the formation of characteristic aroma compounds of yoghurt (Germani et al., 2014). Various factors such as milk type, heat treatment, fermentation, and microorganism

**Table 3**
The amino acid profile (g 100 $g^{-1}$ protein) and ACE inhibitory activity (%) of the experimental yoghurt samples.[a]

| Component | Yoghurt | | | | | Sig. |
|---|---|---|---|---|---|---|
| | Buffalo | Camel | Cow | Goat | Sheep | |
| Arginine | $3.52 \pm 0.04^{d}$ | $4.31 \pm 0.07^{a}$ | $3.72 \pm 0.01^{b}$ | $3.54 \pm 0.06^{cd}$ | $3.64 \pm 0.02^{bc}$ | ** |
| Histidine | $2.65 \pm 0.02^{c}$ | $2.64 \pm 0.04^{b}$ | $3.17 \pm 0.03^{a}$ | $2.11 \pm 0.02^{d}$ | $2.36 \pm 0.05^{c}$ | ** |
| Isoleucine | $5.89 \pm 0.01^{a}$ | $5.17 \pm 0.03^{d}$ | $5.72 \pm 0.04^{b}$ | $5.73 \pm 0.06^{b}$ | $5.57 \pm 0.02^{c}$ | ** |
| Leucine | $9.94 \pm 0.05^{a}$ | $9.55 \pm 0.05^{c}$ | $9.21 \pm 0.01^{d}$ | $9.61 \pm 0.01^{c}$ | $9.84 \pm 0.01^{b}$ | ** |
| Lysine | $8.30 \pm 0.08^{b}$ | $8.59 \pm 0.02^{a}$ | $8.09 \pm 0.04^{c}$ | $8.14 \pm 0.06^{c}$ | $8.46 \pm 0.04^{a}$ | ** |
| Methionine | $2.10 \pm 0.06^{c}$ | $2.08 \pm 0.02^{c}$ | $3.33 \pm 0.05^{a}$ | $2.87 \pm 0.02^{b}$ | $1.86 \pm 0.01^{d}$ | ** |
| Phenylalanine | $4.33 \pm 0.04^{c}$ | $5.15 \pm 0.01^{a}$ | $3.97 \pm 0.04^{e}$ | $4.18 \pm 0.06^{d}$ | $4.46 \pm 0.03^{b}$ | ** |
| Threonine | $7.05 \pm 0.02^{c}$ | $5.82 \pm 0.04^{d}$ | $5.26 \pm 0.01^{e}$ | $7.79 \pm 0.05^{a}$ | $7.63 \pm 0.01^{b}$ | ** |
| Tryptophan | $2.39 \pm 0.04^{b}$ | $2.80 \pm 0.10^{a}$ | $1.92 \pm 0.09^{c}$ | $2.14 \pm 0.08^{c}$ | $2.54 \pm 0.11^{b}$ | ** |
| Valine | $6.58 \pm 0.07^{a}$ | $6.70 \pm 0.02^{a}$ | $6.21 \pm 0.01^{c}$ | $6.34 \pm 0.05^{bc}$ | $6.42 \pm 0.08^{b}$ | ** |
| Alanine | $4.74 \pm 0.04^{b}$ | $2.71 \pm 0.01^{e}$ | $3.64 \pm 0.06^{c}$ | $4.96 \pm 0.02^{a}$ | $3.23 \pm 0.05^{d}$ | ** |
| Asparagine | $2.59 \pm 0.12^{a,b}$ | $2.48 \pm 0.04^{a,b}$ | $2.17 \pm 0.15^{c}$ | $2.38 \pm 0.08^{bc}$ | $2.74 \pm 0.06^{a}$ | * |
| Aspartic acid | $5.59 \pm 0.06^{e}$ | $6.75 \pm 0.02^{b}$ | $7.14 \pm 0.03^{a}$ | $6.58 \pm 0.05^{c}$ | $6.31 \pm 0.01^{d}$ | ** |
| Cystine | $2.23 \pm 0.02^{a}$ | $1.32 \pm 0.01^{c}$ | $1.14 \pm 0.06^{d}$ | $1.54 \pm 0.13^{b}$ | $1.36 \pm 0.03^{c}$ | ** |
| Glycine | $1.41 \pm 0.03^{e}$ | $1.63 \pm 0.07^{d}$ | $2.35 \pm 0.02^{b}$ | $2.64 \pm 0.11^{a}$ | $2.57 \pm 0.04^{a}$ | ** |
| Glutamic acid | $10.72 \pm 0.09^{c}$ | $13.08 \pm 0.17^{a}$ | $12.54 \pm 0.04^{b}$ | $10.80 \pm 0.11^{c}$ | $11.00 \pm 0.08^{c}$ | ** |
| Proline | $9.55 \pm 0.02^{c}$ | $11.46 \pm 0.01^{a}$ | $9.19 \pm 0.04^{d}$ | $9.46 \pm 0.05^{c}$ | $10.39 \pm 0.07^{b}$ | ** |
| Serine | $4.87 \pm 0.06^{b}$ | $3.57 \pm 0.04^{d}$ | $6.04 \pm 0.01^{a}$ | $4.32 \pm 0.08^{c}$ | $4.88 \pm 0.04^{b}$ | ** |
| Tyrosine | $4.15 \pm 0.05^{a}$ | $2.61 \pm 0.06^{e}$ | $3.13 \pm 0.06^{c}$ | $2.82 \pm 0.02^{d}$ | $3.27 \pm 0.00^{b}$ | ** |
| ACE inhibitory activity | $36.21 \pm 0.05^{c}$ | $41.54 \pm 0.46^{a}$ | $33.15 \pm 0.34^{e}$ | $35.32 \pm 0.42^{d}$ | $39.64 \pm 0.26^{b}$ | ** |

[a] Different superscript letters in a row indicate significant differences: **, $P < 0.01$; *, $P < 0.05$; Sig., significance.

activity are effective in the differences in amino acid profile in products such as yoghurt (Landi, Ragucci, & Di Maro, 2021).

Boukria et al. (2020) reported that the predominant amino acids in different animal milk types are leucine, glutamic acid, and proline. These researchers reported that leucine contents in the milk of buffalo, camel, cow, goat and sheep were 8.74–8.97 g 100 $g^{-1}$ protein, 9.5–10.4 g 100 $g^{-1}$ protein, 9.44–10.4 g 100 $g^{-1}$ protein, 8.7–9.8 g 100 $g^{-1}$ protein and 9.7–9.9 g 100 $g^{-1}$ protein, respectively. They stated that the glutamic acid contents in the milk of buffalo, camel, cow, goat and sheep were 19.36–19.64 g 100 $g^{-1}$ protein, 19.5–23.9 g 100 $g^{-1}$ protein, 19.66–21.8 g 100 $g^{-1}$ protein, 5.23–23.2 g 100 $g^{-1}$ protein and 14.5 g 100 $g^{-1}$ protein, respectively. Boukria et al. (2020) also reported that the proline contents in the milk of buffalo, camel, cow, goat and sheep were 9.21–9.32 g 100 $g^{-1}$ protein, 11.1–13.0 g 100 $g^{-1}$ protein, 8.99–10.0 g 100 $g^{-1}$ protein, 8.93–9.60 g 100 $g^{-1}$ protein and 16.2 g 100 $g^{-1}$ protein, respectively. In this context, in addition to the variability of the amino acid profiles of different animal milk types used as raw materials in the current research, differences in heat treatment, fermentation and microorganism activities are thought to be effective in the amino acid profiles of experimental yoghurt samples.

Wang et al. (2023) reported in their research that the essential amino acid/total amino acid ratio of yoghurt samples was over 40% and if the essential amino acid/total amino acid value is above this ratio, they can have ideal protein standards recommended by the Food and Agriculture Organisation (FAO)/World Health Organisation (WHO). In this context, while the essential amino acid/total amino acid ratio in the camel yoghurt was determined as 53.65%, it was determined as 53.57% in the sheep yoghurt, 53.55% in the goat yoghurt, 53.50% in the buffalo yoghurt, and 51.66% in the cow yoghurt. As a result, yoghurt is a potential source that can eliminate dietary deficiencies with its high biological value protein content and essential amino acids.

The most common bioactivity in peptides identified in dairy products is expressed as ACE inhibitory activity (Nielsen, Jakobsen, Geiker, & Bertram, 2022). ACE plays a role in the treatment of hypertension by inhibiting the vasoconstrictor angiotensin II secretion and preventing the breakdown of the vasodilator bradykinin. The ACE inhibitory activity of yoghurt is provided by the proteolytic activities of lactic acid bacteria during fermentation (Garavand, Daly, & Gómez-Mascaraque, 2022; Hermanto, Hatiningsih, & Putera, 2018; Sultan, Huma, Butt, & Shahid, 2017).

The ACE inhibitory activity of the camel yoghurt was determined as 41.54%, while it was determined as 39.64% in the sheep yoghurt, 36.21% in the buffalo yoghurt, 35.32% in the goat yoghurt, and 33.15% in the cow yoghurt. In addition to protein content, amino acid content also has a significant effect on ACE inhibitory activity in yoghurt. ACE inhibitory activity in yoghurt is formed by the proteolytic activity of lactic acid bacteria during fermentation. However, amino acids located at the C-terminal residue of peptides with ACE inhibitory activity have a key role in binding to ACE. In this context, it has been reported that bioactive peptides with ACE inhibitory activity exhibit an effective activity when hydrophobic amino acids such as proline, valine, phenylalanine, tryptophan, and tyrosine are present at the C-terminal. It was also emphasised that the presence of positively charged lysine at the C-terminal of the peptide resulted in a high ACE inhibitory activity (Alhaj, 2017; Shi, Ahtesh, Mathai, McAinch, & Su, 2017). As a matter of fact, in the current research, the highest ACE inhibitory activity was detected in camel yoghurt, which contains the highest proportion of proline, lysine, phenylalanine, and tryptophan, which are amino acids that play an active role in ACE inhibitory activity, and ACE inhibitory activity values were listed in parallel with these amino acid contents in all yoghurts.

### 3.4. Organic acid profile

In the current research, the content of a total of 7 organic acids, i.e., citric acid, hippuric acid, lactic acid, orotic acid, pyruvic acid, tartaric acid, and uric acid, were examined in the yoghurt samples produced from different milk types. The LOD and LOQ values calculated according to the signal/noise ratios in determining the organic acid profile are given in theSupplementary material Table S2. The organic acid profile of buffalo, camel, cow, goat, and sheep yoghurt samples is given in Table 4. It was determined that the use of different animal milk types in yoghurt production had a very significant effect ($P < 0.01$) on citric and orotic acids, while it did not have a statistically significant effect ($P > 0.05$) on other organic acids. Citric acid, which is formed as an intermediate product in the oxidation of acetate in the citric acid cycle (Milsom, 1987), was determined as 274.29 mg 100 $g^{-1}$ in the camel yoghurt, while it was found as 314.88 mg 100 $g^{-1}$ in the cow yoghurt, 288.13 mg 100 $g^{-1}$ in the sheep yoghurt, 279.42 mg 100 $g^{-1}$ in the buffalo yoghurt, and 274.63 mg 100 $g^{-1}$ in the goat yoghurt, in the current research. Citric acid, which is found at an average level of 0.2% in milk, is characterised as a natural organic acid found mostly in fruits and vegetables (Ndhlala, Kavaz Yüksel, & Yüksel, 2022).

Hippuric acid produced by starter cultures during fermentation is essentially one of the non-protein nitrogen compounds of milk. After hippuric acid is produced in fermentation, it turns into benzoic acid and this transformation has an effect on the shelf life of yoghurt (Fernandez-Garcia & McGregor, 1994; Heller, 2001; Qi, Hong, Liang, & Liu, 2009). In the present study, it was determined that the hippuric acid contents of the yoghurt samples produced from different milk types were statistically similar. Hippuric acid content, which was determined as 0.40 mg 100 $g^{-1}$ in the camel yoghurt, was determined as 0.39 mg 100 $g^{-1}$ in the cow, goat, and sheep yoghurt samples, and 0.36 mg 100 $g^{-1}$ in the buffalo yoghurt.

Lactic acid, which is formed by the use of glucose or fructose by lactic acid bacteria, causes an acidic and sharp taste in the product. The formation of lactic acid, which is the main organic acid of yoghurt, begins with the transport of lactose into the cell with the phosphotransferase enzyme by *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus* and its breakdown into glucose and galactose by the β-D-galactosidase enzyme. Afterward, glucose is converted to pyruvic acid by the way of Embden Meyerhof and Parnas (EMP), and lactic acid is formed from the formed pyruvic acid by the lactate dehydrogenase enzyme. It is reported that lactic acid, which has a significant effect on the sensory properties of yoghurt, has optimum sensory properties if it is present at the level of 7–9 mg $g^{-1}$ (Deshwal, Tiwari, Kumar, Raman, & Kadyan, 2021; Silva et al., 2023). It was determined that the yoghurts produced in this study contained lactic acid at a level close to this value. In our study, lactic acid, which is the dominant organic acid, was determined at the level of 926.50 mg 100 $g^{-1}$ in the camel yoghurt, while it was determined as 966.86 mg 100 $g^{-1}$ in the sheep yoghurt, 947.86 mg 100 $g^{-1}$ in the goat yoghurt, 932.06 mg 100 $g^{-1}$ in the buffalo yoghurt, and 925.12 mg 100 $g^{-1}$ in the cow yoghurt. On the other hand, it was determined that the lactic acid content of the yoghurts produced using different animal milk types was statistically not different from each other ($P > 0.05$). This shows that all yoghurts produced are similar in terms of sensory properties.

Orotic acid, which occurs as an intermediate product in pyrimidine biosynthesis, is present at significant levels in the milk of ruminant animals. It is reported that orotic acid, which is effective in reducing the incidence of cholesterolemia, also has a stimulating effect on the growth of yoghurt bacteria (Fernandez-Garcia & McGregor, 1994; Ndhlala et al., 2022; Urbienė & Leskauskaitė, 2006). In the present study, the highest orotic acid content was determined in the camel yoghurt (118.09 mg 100 $g^{-1}$), followed

**Table 4**
The organic acid profile (mg 100 $g^{-1}$) of the experimental yoghurt samples.[a]

| Acid | Yoghurt | | | | | Sig. |
|---|---|---|---|---|---|---|
| | Buffalo | Camel | Cow | Goat | Sheep | |
| Citric acid | 279.42 ± 8.16[b] | 274.29 ± 1.77[b] | 314.88 ± 3.34[a] | 274.63 ± 4.04[b] | 288.13 ± 6.01[b] | ** |
| Hippuric acid | 0.36 ± 0.00[a] | 0.40 ± 0.00[a] | 0.39 ± 0.01[a] | 0.39 ± 0.00[a] | 0.39 ± 0.03[a] | ns |
| Lactic acid | 932.06 ± 24.33[a] | 926.50 ± 5.86[a] | 925.12 ± 23.14[a] | 947.86 ± 14.95[a] | 966.86 ± 17.95[a] | ns |
| Orotic acid | 112.26 ± 2.93[ab] | 118.09 ± 6.11[a] | 106.06 ± 4.55[b] | 61.35 ± 1.71[d] | 73.54 ± 2.61[c] | ** |
| Pyruvic acid | 23.13 ± 2.38[a] | 21.37 ± 1.68[a] | 22.31 ± 0.51[a] | 21.08 ± 1.21[a] | 22.05 ± 1.85[a] | ns |
| Tartaric acid | 0.92 ± 0.04[a] | 0.92 ± 0.04[a] | 0.88 ± 0.01[a] | 0.89 ± 0.01[a] | 0.90 ± 0.03[a] | ns |
| Uric acid | 18.04 ± 2.57[a] | 15.65 ± 2.74[a] | 17.81 ± 3.71[a] | 13.67 ± 1.02[a] | 16.47 ± 3.10[a] | ns |

[a] Different superscript letters in a column indicate significant differences: **, $P < 0.01$; ns, $P > 0.05$; Sig., significance.

by ≥ buffalo yoghurt (112.26 mg 100 $g^{-1}$) ≥ cow yoghurt (106.06 mg 100 $g^{-1}$) > sheep yoghurt (73.54 mg 100 $g^{-1}$) > goat yoghurt (61.35 mg 100 $g^{-1}$). Pyruvic acid, which is produced by carbohydrate and protein metabolism, can be transformed into lactic acid or some other metabolites with further reactions (Ndhlala et al., 2022). It was determined that the pyruvic acid contents of the yoghurts produced in the present study did not show a statistical difference ($P > 0.05$). At the same time, in the present study, it was determined that the yoghurt samples produced from different milk types were not statistically different from each other in terms of tartaric acid and uric acid contents.

It has been reported that differences in organic acid content can be seen in different animal milk types. Buffa, Guamis, Saldo, and Trujillo (2004) reported that the amount of citric acid in goat milk was 37.2 mg $kg^{-1}$ total solids, the amount of lactic acid was 303.4 mg $kg^{-1}$ total solids, the amount of pyruvic acid was 0.5 mg $kg^{-1}$ total solids and the amount of uric acid was 0.5 mg $kg^{-1}$ total solids. Haddadin, Gammoh, and Robinson (2008) reported that the average amount of orotic acid in camel milk was 76.1 mg $L^{-1}$, the amount of hippuric acid was 10.2 mg $L^{-1}$, the amount of citric acid was 846 mg $L^{-1}$ and the amount of pyruvic acid was 5.4 mg $L^{-1}$. Rodrigues (2013) reported that the orotic acid content of buffalo milk was 19.6 μg 100 $mL^{-1}$, while orotic acid content of cow milk was 52.6 μg 100 $mL^{-1}$.

It is reported that the organic acids found in yoghurt contribute to microbial safety as natural protective components, as well as contribute to sensory properties with their natural aromas and their transformation into various aroma components such as aldehydes, ketones, and alcohols by advanced reactions (Batista et al., 2017; Vénica, Perotti, & Bergamini, 2014). It has been reported that organic acids such as lactic acid and pyruvic acid are formed through bacterial metabolism, while organic acids such as citric acid, orotic acid, and uric acid are formed through the biochemical metabolism of the animal (Vénica et al., 2014). As in the studies conducted on the organic acid profile in yoghurts (Batista et al., 2017; Silva et al., 2023), it was determined that lactic acid is the dominant organic acid in the current study. Khaliq et al. (2022) reported that the citric acid content in camel yoghurt varied between 6042 and 8589 mg $L^{-1}$ and the lactic acid content varied between 6918 and 6996 mg $L^{-1}$. Ale et al. (2023) determined the contents of lactic acid, orotic, and citric acid as 543 mg 100 $g^{-1}$, 24 mg 100 $g^{-1}$, and 140 mg 100 $g^{-1}$, respectively, in yoghurt samples produced using *S. thermophilus* and *L. delbrueckii* subsp. *bulgaricus* cultures. However, it is thought that the starter culture type, milk type, additives, fermentation, and storage conditions are effective in the differences between the studies in the literature and the current research data (Vénica et al., 2014).

### 3.5. Textural and rheological properties

In the yoghurt samples produced from different animal milk types, firmness, consistency, and cohesiveness parameters for texture analysis and yield stress τ0, consistency k, and flow index parameters for rheology analysis were investigated during the storage period. The textural and rheological properties of the buffalo, camel, cow, goat, and sheep yoghurt samples are given in Table 5.

The use of different animal milk types in yoghurt production and the storage period had a very significant effect ($P < 0.01$) on the firmness, consistency, and cohesiveness parameters. In yoghurt samples, the firmness value, which expresses the maximum compression force on the probe of the device, the consistency value, which describes the lower area of the curve that occurs in forward extrusion, and the cohesiveness value, which describes the maximum force that occurs when the probe is pulled, were determined at the highest level in the sheep yoghurt and the lowest level in the goat yoghurt. Hovjecki et al. (2021) reported that the denaturation of serum proteins due to heat treatment in yoghurt samples changed gel firmness and the interaction of serum proteins and casein micelles. In the texture analysis of the yoghurt samples, the overall parameter values examined were determined to increase as the storage time increased. It is thought that these increases in the storage process of yoghurt are due to the combination of microgels to form new structures (Gilbert & Turgeon, 2021). On the other hand, the high total solids and protein content in yoghurt increases water binding, leading to a stronger protein network, and as a result, an increase in firmness value occurs (Basiri, Tajbakhsh, & Shekarforoush, 2022).

In the current study, it is thought that total solids and protein content are effective in exhibiting better textural properties of sheep yoghurt. On the other hand, the weak textural properties in goat yoghurt are thought to be due to the fact that goat milk contains lower levels of $\alpha_{S1}$-casein, the β-casein solubility is higher, the sedimentation rate of casein micelles is low, the calcium and phosphorus content is higher, and its thermal stability is low compared with other milk types (Moschopoulou et al., 2018). In general, it is thought that factors such as milk type, starter culture, heat treatment, fermentation, and storage conditions that affect the gel structure play a role in the differences in the textural properties of yoghurt samples (Costa et al., 2015).

It was determined that the use of different animal milk types in the yoghurt production had a very significant effect ($P < 0.01$) on yield stress τ0 and consistency k values, while it did not have a significant effect ($P > 0.05$) on the flow index value. It was determined that the storage period had a very significant effect ($P < 0.01$) on yield stress τ0, while it was found that it did not have a significant effect ($P > 0.05$) on consistency k and flow index values. In the present study, the highest yield stress τ0 value was determined in the sheep and buffalo yoghurts; the highest consistency k value was determined in the sheep yoghurt, and the lowest yield stress τ0 and consistency k values were determined in the goat yoghurt. Yield stress τ0, which is characterised as one of the characteristic features of yoghurt included in the class of pseudoplastic products, is expressed as a function of the increase in the slip rate. Also, yield

**Table 5**
The textural and rheological analyses of the experimental yoghurt samples.[a]

| Parameter | Firmness (N) | Consistency (N s) | Cohesiveness (N) | Yield stress τ0 (Pa) | Consistency index, k (Pa $s^n$) | Flow index, n |
|---|---|---|---|---|---|---|
| Yoghurt type | | | | | | |
| Buffalo | 3.56 ± 0.24$^b$ | 34.04 ± 2.06$^b$ | 2.13 ± 0.06$^b$ | 5.81 ± 0.32$^a$ | 6.03 ± 0.22$^b$ | 0.27 ± 0.03$^a$ |
| Camel | 2.30 ± 0.17$^d$ | 26.06 ± 2.41$^d$ | 1.54 ± 0.14$^d$ | 4.32 ± 0.21$^c$ | 5.20 ± 0.08$^d$ | 0.27 ± 0.03$^a$ |
| Cow | 3.14 ± 0.29$^c$ | 32.62 ± 2.35$^c$ | 1.71 ± 0.16$^c$ | 5.05 ± 0.52$^b$ | 5.49 ± 0.13$^c$ | 0.27 ± 0.02$^a$ |
| Goat | 1.68 ± 0.25$^e$ | 18.14 ± 2.11$^e$ | 1.25 ± 0.12$^e$ | 0.79 ± 0.13$^d$ | 4.16 ± 0.31$^e$ | 0.26 ± 0.03$^a$ |
| Sheep | 4.12 ± 0.22$^a$ | 38.99 ± 2.27$^a$ | 2.25 ± 0.07$^a$ | 6.07 ± 0.23$^a$ | 6.34 ± 0.10$^a$ | 0.27 ± 0.02$^a$ |
| Sig. | ** | ** | ** | ** | ** | ns |
| Storage period (days) | | | | | | |
| 1 | 2.76 ± 0.92$^c$ | 27.73 ± 7.76$^c$ | 1.74 ± 0.43$^b$ | 4.64 ± 2.13$^a$ | 5.50 ± 0.77$^a$ | 0.27 ± 0.02$^a$ |
| 7 | 2.92 ± 0.95$^b$ | 29.84 ± 7.56$^b$ | 1.76 ± 0.40$^b$ | 4.39 ± 1.97$^b$ | 5.40 ± 0.78$^a$ | 0.26 ± 0.02$^a$ |
| 14 | 3.20 ± 0.91$^a$ | 32.34 ± 7.64$^a$ | 1.83 ± 0.38$^a$ | 4.19 ± 1.96$^b$ | 5.43 ± 0.89$^a$ | 0.26 ± 0.03$^a$ |
| Sig. | ** | ** | ** | ** | ns | ns |

[a] Different superscript letters in a column indicate significant differences: **, $P < 0.01$; ns, $P > 0.05$; Sig., significance.

stress τ0 characterises an interactive or cross-linked structure (Costa et al., 2019).

The value of flow index n, which expresses the degree of non-Newtonian fluid properties, characterises the fluid that exhibits slip thinning (pseudoplastic) when it is <1, while it characterises the fluid that thickens with shear when it is >1 (Delgado et al., 2020). In this context, the fact that the flow index n value of all yoghurt samples produced from different animal milk types in the current research is <1 supports that the yoghurt produced behaves as a non-Newtonian liquid exhibiting pseudoplastic behaviour. It is reported that the orientation of components such as protein and fat towards the direction of liquid movement is also effective in reducing the resistance to flow in yoghurt (Costa et al., 2015).

### 3.6. Correlation analysis and discrimination of yoghurt samples using PCA

Correlation analysis of various physicochemical, biochemical, textural, and rheological properties of the yoghurt samples is performed inSupplementary material Fig. S1. A positive correlation was determined between total solid and fat content (r = 0.994, $P < 0.01$), protein content (r = 0.917, $P < 0.01$), ash content (r = 0.915, $P < 0.01$), ∑SFA content (r = 0.836, $P < 0.01$), cholesterol (r = 0.946, $P < 0.01$), leucine (r = 0.818, $P < 0.01$), asparagine (r = 0.864, $P < 0.01$), firmness (r = 0.826, $P < 0.01$), consistency (r = 0.753, $P < 0.05$), cohesiveness (r = 0.742, $P < 0.05$), consistency index k (r = 0.790, $P < 0.01$), while a negative correlation was determined between total solid and stearic acid content (r = −0.790, $P < 0.01$), linoleic acid (r = −0.677, $P < 0.05$), methionine (r = −0.784, $P < 0.01$), aspartic acid (r = −0.707, $P < 0.05$). It has been shown by various studies that the physicochemical properties of yoghurt are related to the gel microstructure and that fat, protein, ash and firmness values increase proportionally as the total solids ratio increases in yoghurt (Terzioğlu & Bakırcı, 2023; Yeganehzad, Mazaheri-Tehrani, & Shahidi, 2007). In addition, a positive correlation was stated between fat globule diameter and gel formation, and it was stated that yoghurts produced from milk types with smaller fat globule diameter, such as goat milk, had a lower firmness value (Vargas, Cháfer, Albors, Chiralt, & González-Martínez, 2008).

There was a negative correlation between ACE inhibitory activity and titratable acidity (r = −0.935, $P < 0.01$), oleic acid (r = −0.974, $P < 0.01$), ∑MUFA (r = −0.719, $P < 0.05$), isoleucine (r = −0.787, $P < 0.01$), methionine (r = −0.831, $P < 0.01$), alanine (r = −0.652, $P < 0.05$), serine (r = −0.758, $P < 0.05$), while there was a positive correlation between ACE inhibitory activity and pH (r = 0.961, $P < 0.01$), myristic acid (r = 0.825, $P < 0.01$), ∑PUFA (r = 0.684, $P < 0.05$), arginine (r = 0.658, $P < 0.05$), lysine (r = 0.972, $P < 0.01$), phenylalanine (r = 0.929, $P < 0.01$), tryptophan (r = 0.969, $P < 0.01$), valine (r = 0.766, $P < 0.01$), asparagine (r = 0.659, $P < 0.05$), proline (r = 0.959, $P < 0.01$).

Chamata, Watson, and Jauregi (2020) reported that dipeptides containing positively charged amino acids such as arginine and lysine and hydrophobic amino acids such as phenylalanine, tryptophan, and valine have strong ACE inhibitory activity. In addition, the researchers emphasised that tripeptides with aromatic amino acids at the C-terminal, positively charged amino acids in the middle of the chain and hydrophobic amino acids at the N-terminal exhibit stronger ACE inhibitory activity. They also mentioned that the presence of proline or hydrophobic amino acids at the carboxyl end of the chain results in both strong and digest-resistant ACE inhibitory activity.

A positive correlation between was determined between cholesterol content and total solid content (r = 0.946, $P < 0.01$), fat content (r = 0.932, $P < 0.01$), protein content (r = 0.955, $P < 0.01$), ash content (r = 0.945, $P < 0.01$), ∑SFA (r = 0.968, $P < 0.01$), and firmness (r = 0.662, $P < 0.05$), while a negative correlation was determined between cholesterol content and stearic acid (r = −0.751, $P < 0.05$), and ∑MUFA (r = −0.635, $P < 0.05$). There are several studies in the literature that indicate a positive correlation between fat content and cholesterol content in dairy products. Talpur, Bhanger, and Memon (2008) reported that the cholesterol content in dairy products was positively correlated with the fat content of the milk used in production. Voblikova, Permyakov, Rostova, Masyutina, and Eliseeva (2020) reported that the relationship between polyunsaturated fatty acids and saturated fatty acids can be used as a factor on the cholesterol level in the blood plasma, and that cholesterol and saturated fatty acids are directly related.

PCA was applied to illustrate the differences between the yoghurt samples by evaluation of their various physicochemical, biochemical, textural, and rheological properties. The score scatterplot, dendrogram (hierarchical clustering), loading scatter plot, and biplot for the yoghurt samples are shown in Fig. 1A–D, respectively.

The first two principal components (PC1 = 35.2% and PC2 = 34%) accounted for 69.2% of the variance. The buffalo and sheep yoghurts were well separated from other yoghurts (Fig. 1A), indicating that they had some differences. It was also determined that cow and goat yoghurts showed similar properties with each other, buffalo and sheep yoghurts with each other, on the other hand, camel yoghurt showed different properties from buffalo and sheep yoghurts and similar properties to cow and goat yoghurts (Fig. 1B). Total solid, fat, protein, ash, ∑SFA, cholesterol, leucine, asparagine, firmness, consistency, cohesiveness, and consistency index k were clustered together at the lower right side of the plot, indicating that there was a positive correlation between them (Fig. 1C). ACE, pH, myristic acid, ∑PUFA, arginine, lysine, phenylalanine, tryptophan,

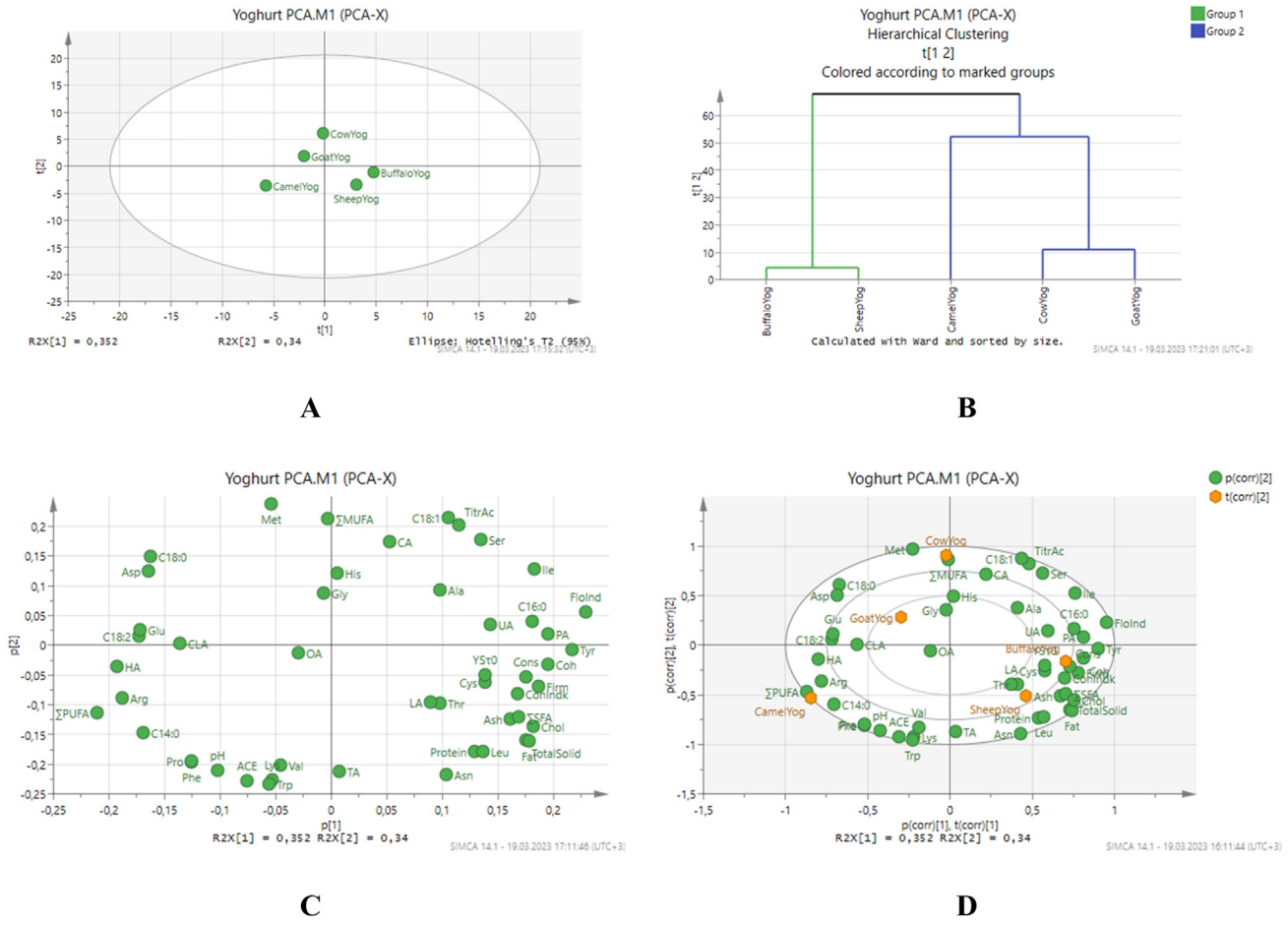


**Fig. 1.** Score scatter plot (A), dendrogram (hierarchical clustering) (B), loading scatter plot (C) and biplot (D) of PCA analysis (PC1 versus PC2) for the components in the yoghurts.

valine, asparagine, proline were clustered together at the lower left side of the plot, indicating that there was a positive correlation between them (Fig. 1C). Total solid, fat, protein, ash, ∑SFA, cholesterol, were located at the lower right side of the plot, indicating that sheep yoghurt and buffalo yoghurt contained higher levels of these components compared with the other yoghurt samples (Fig. 1D). Titratable acidity, oleic acid, ∑MUFA, histidine, methionine, serine, and citric acid were clustered together, indicating that cow yoghurt contained higher levels of these components compared with the other yoghurt samples (Fig. 1D). In addition, pH, myristic acid, arginine, phenylalanine, ACE inhibitory activity were clustered together, indicating that camel yoghurt contained higher levels of these components compared with the other yoghurt samples (Fig. 1D).

As a matter of fact, there are studies revealing that buffalo and sheep milk and yoghurts produced from these milk sources exhibit similar properties in terms of physicochemical properties (total solid content, fat content, protein content, ash content, pH and titratable acidity value) associated with the nutritional, textural, and rheological properties of the final product (Boukria et al., 2020; Terzioğlu & Bakırcı, 2023). On the other hand, it is determined that cow and goat milk and the yoghurts produced from cow and goat milk have similar values in terms of total solids content, fat content, protein content, pH and titratable acidity value (Balthazar et al., 2016; Terzioğlu, 2022). Khalifa and Zakaria (2019) reported that camel and goat yoghurts showed relatively similar properties compared with buffalo yoghurt in their research examining the physicochemical properties of buffalo, camel and goat yoghurts.

## 4. Conclusion

In the current study, physicochemical and biochemical properties (fatty acid composition, cholesterol content, amino acid profile, ACE inhibitory activity, and organic acid profile), textural and rheological properties of the camel yoghurt and the yoghurts produced with 4 different animal milk types (buffalo, cow, goat, and sheep) were determined and compared with each other.

Significant differences were observed in the yoghurts produced with different animal milk types in terms of the properties examined, and it was evaluated that these differences were largely due to the composition of the milk and fermentation. It was determined that the richest yoghurt sample in terms of total solids, fat, and protein content was sheep yoghurt, while the lowest content in terms of these components was found in cow yoghurt. When the fatty acid composition and cholesterol content were assessed, the highest ∑SFA and cholesterol content were found in the sheep yoghurt, ∑MUFA content in the cow yoghurt, and ∑PUFA content in the goat yoghurt. The lowest CLA content was determined in the sheep yoghurt.

In the yoghurt samples, it was determined that the most dominant essential amino acid was leucine, and the most dominant non-essential amino acid was glutamic acid. The ACE inhibitor activity value associated with amino acids such as proline, phenylalanine, and tryptophan, along with bioactive peptides, came to the fore in camel yoghurt, which contains these amino acids at the highest level. It was determined that the produced yoghurts did not have a significant difference in terms of lactic acid content, which is

the most dominant organic acid. The highest firmness, consistency, cohesiveness, yield stress τ0, and consistency index values were determined in the sheep yoghurt.

To sum up, when a general evaluation is made, it has been observed that yoghurt, which already has unique properties, gains different physicochemical, biochemical, textural, and rheological properties by obtaining it from different animal milk types, and it seems attractive to use different types of milk to increase its functionality.

## Author contributions

Conceptualization, M.E.T.; methodology, M.E.T., I.B., E.O., and F.O.; validation, M.E.T., and F.O.; formal analysis, M.E.T; investigation, M.E.T., I.B., E.O., C.B., T.H., R.A., and F.O.; data curation, M.E.T.; writing—original draft preparation, M.E.T., I.B., E.O., C.B., T.H., R.A., M.R.K., T.E., R.M.A., and F.O.; writing—review and editing, M.E.T., I.B., E.O., C.B., T.H., R.A., M.R.K., T.E., R.M.A., and F.O.; visualization, M.E.T. and F.O.; supervision, M.E.T., and F.O.; project administration, M.E.T. All authors have read and agreed to the published version of the manuscript.

## Declaration of competing interest

The authors have no conflict of interest.

## Data availability

Data will be made available on request.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.idairyj.2023.105749.

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