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DEVELOPMENT AND OPTIMIZATION OF TECHNOLOGY OF SOFT CHEESE PRODUCTION FROM CAMEL MILK

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The object of this study is the soft cheese production from camel milk (Camelus dromedarius), with a specific focus on curd formation and the structural and quality characteristics of the final product.

The study addresses a key problem, namely it's the weak gelation and unstable curd structure of camel milk, resulting from its atypical protein composition, which complicates its use in cheese making. The main task was to identify optimal values of coagulant dose and coagulation temperature to enhance both cheese yield and quality.

Experimental studies evaluated the effects of ChyMax® M 1000 at doses of 0.05–0.20 ml/l and coagulation temperatures of 34–40°C on key technological indicators such as yield, syneresis, moisture retention, and textural attributes. Both factors significantly influenced the development of curd and final product quality. The most favorable results were obtained at a coagulant dose of 0.10–0.15 ml/l and a coagulation temperature of 36–38°C. Under these conditions, cheese yield reached up to 184.5 g/l, with improved moisture content (up to 60.5%), moderate syneresis, and enhanced textural characteristics. These outcomes are attributed to increased proteolytic activity and improved gel matrix formation at the optimal conditions. The key distinguishing feature of the results is the identified balance of coagulant dose and temperature, which led to stable curd structure and higher cheese yield.

A technological scheme for the soft cheese production from camel milk was developed, offering potential for industrial-scale application. The proposed process is suitable for dairy enterprises seeking to diversify their product range with functional and regionally adapted soft cheeses based on camel milk

Keywords: camel milk, soft cheese, coagulation temperature, coagulant dose, cheese yield

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1. Introduction

The dairy industry is changing worldwide, driven by the growing demand for sustainable, nutritious, and culturally appropriate products. Camel milk is emerging as a promising alternative to cow's milk due to its unique biochemical composition, high digestibility, and potentially health-promoting properties. It is rich in bioactive substances, including immunoglobulins, lysozyme, and insulin-like proteins, and contains less lactose and allergenic proteins, making it suitable for people with cow's milk intolerance and a range of metabolic disorders. These properties are driving the increasing scientific and commercial interest in camel milk products, particularly in arid and semi-arid regions where camels have traditionally served as the primary source of milk.

However, the production of cheese from camel's milk remains a technological challenge. Camel milk has a different casein micelle structure, less κ-casein and a higher buffering capacity than cow's milk, which hinders coagulation and curdling and reduces the yield of the final product. These differences require the development of specific approaches to cheesemaking technology, including the selection of effective enzymes, coagulation parameters, and adaptation of process flows to achieve the desired texture, moisture content, and protein content.

In addition, increasing urbanization and demand for functional and ethno-culturally relevant dairy products in the Middle East, North and Central Africa, and Central Asia highlight the need for localized and optimized technological solutions for camel milk cheese production. The availability of replicable and scalable technologies in this area will contribute to food security and the development of the local dairy industry and ensure the production of value-added products for export to markets focused on healthy nutrition and ethnic diversity.

Given that the technological limitations in processing camel milk are still much less researched compared to cow's milk, it is impossible to fully realize the potential of camel milk for the production of high-quality dairy products.

Therefore, research aimed at the development of technology for the soft cheese production from camel milk is relevant.

2. Literature review and problem statement

In recent years, interest in camel milk as a valuable food product has increased significantly, especially in arid climate

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countries, especially in arid and semi-arid regions. These areas are characterized by low rainfall, high temperatures and limited pasture productivity, which make camel farming more sustainable than other livestock production [1].

In paper [2] present the results of industrial soft cheese production from camel milk with dry and brine salts. The study is valuable because it is carried out under real production conditions, with standardized technological steps and subsequent evaluation of the yield, organoleptic properties and microbiological safety of the products. The authors emphasized that soft cheeses made from camel milk exhibit satisfactory quality when coagulation process parameters and a suitable salting strategy are followed. The advantage of the study is its practical orientation and the use of pasteurized milk, which brings the conditions closer to industrial realities. However, the work did not consider the effect of varying technological parameters (coagulant dosage, coagulation temperature) on texture characteristics, nor did it quantify syneresis and curd structure, which limits the depth of scientific conclusions.

The paper [3] explores the optimization of camel milk coagulation using different coagulants of microbial and vegetable origin. Authors found a significant effect of coagulant dose and coagulation temperature on clot formation and cheese yield. However, the study was limited to pasteurized milk and did not include an analysis of the textural properties of the finished product, which is an important factor for consumer evaluation. Furthermore, the paper [4] investigates the effect of lactic acid bacteria on key stages of camel milk cheese production technology. The authors showed that the choice of starter culture significantly affects texture, flavor and curdling time. The use of *Lactobacillus and Streptococcus thermophilus* strains promoted faster coagulation and improved organoleptic characteristics. However, the study did not include instrumental evaluation of curd texture, which limits the depth of analysis.

The use of lemon juice as a natural coagulant for camel milk cheese production was investigated [5]. The authors showed that acid coagulation can produce a curd with acceptable organoleptic and microbiological characteristics. However, the resulting cheese had poor structural properties due to the limitations of the acid method. The study did not evaluate textural parameters and did not compare the results with conventional rennet enzymes. These limitations highlight the need to optimize enzymatic coagulation parameters such as temperature and enzyme dosage, especially when using raw camel milk, in order to improve the yield and texture of the cheese.

The paper [6] investigated the optimization of camel milk soft cheese production using green carob extract (*Ceratonia siliqua*) as a plant coagulant. The authors systematically evaluated the effects of coagulant dose and coagulation temperature on cheese yield, syneresis, pH, microbial contamination, and rheological and sensory properties. The study showed that the optimum processing parameters significantly improved the curd hardness, yield, and organoleptic evaluation of the finished product. However, the work was carried out on pasteurized milk, and the effect of heat treatment on the preservation of natural bioactive components of camel milk was not taken into account.

The paper [7] investigated the effect of calcium supplementation, coagulation temperature, and lactation stage on the rennet properties of camel milk using recombinant camel chymosin (Chy-Max® M). This study provides valuable information on the processing and biochemical characteristics of camel milk, in particular its sensitivity to processing conditions. Based on a series of comparative experiments, the authors demonstrated that milk coagulation is significantly accelerated at elevated temperatures (36°C), and that heating leads to increased curd firmness. Additionally, the findings reveal that the stage of lactation is a critical determinant of milk's coagulation capacity, with gelation occurring only by the 20th day postpartum. The study further emphasizes a higher rate of acidification at elevated temperatures, indicating a potential influence on curd microstructure. Although these results advance current understanding of camel milk coagulation dynamics, further research is required to optimize processing parameters aimed at improving the yield and textural attributes of camel milk cheese.

The paper [8] investigated the use of recombinant camel chymosin to improve the coagulation and texture of white soft cheese made from camel milk. The study showed improved curd firmness and yield compared to traditional bovine rennet, indicating the suitability of species-specific enzymes. However, there is limited discussion on how the concentration of chymosin and processing parameters (e.g. temperature, incubation time) affect raw milk curd parameters.

Thus, the development of processing parameters for the soft cheese production from raw camel milk remains an unresolved challenge. Addressing this issue would enable increased yield, improved product quality, and better adaptation of the process for industrial-scale production.

3. The aim and objectives of the study

This study aims to develop the technological parameters for the soft cheese production from camel milk (*Camelus dromedarius*). This will make it possible to determine the optimal conditions for enzymatic coagulation, providing effective gel formation, improved syneresis and increased yield of the finished product.

To achieve this aim, the following objectives were accomplished:

– to study the influence of coagulant dose and coagulation temperature on coagulation time (flocculation point) in the soft cheese production from camel milk;

– to determine the influence of coagulant dose and coagulation temperature on syneresis and yield of the finished product;

– to determine the physicochemical properties of soft cheese from camel milk produced under varying conditions;

– to study the textural characteristics of soft cheese from camel milk;

– to develop a technological scheme for producing soft cheese from camel milk.

4. Materials and methods

4. 1. The object and hypothesis of the study

The object of this study is the soft cheese production from camel milk (*Camelus dromedarius*), with a specific focus on curd formation and the structural and quality characteristics of the final product.

The main hypothesis of the study is that the rational parameters of coagulation temperature and coagulant dose (Chy-Max® M 1000) will significantly improve the technological and quality characteristics of soft cheese made from camel milk. Specifically, it is hypothesized that identifying the optimal combination of these parameters will lead to reduced coagulation time, increased cheese yield, and enhanced physicochemical (moisture content, syneresis) and textural properties (hardness, cohesiveness, springiness, gumminess, chewiness, resilience) of the final product.

This work suggests that the use of raw camel milk without prior thermal treatment combined with a coagulation process will allow the development of an efficient soft cheese production technology suitable for industrial implementation. It is also suggested that temperature and coagulant dose are key technological factors affecting the formation of camel milk cheese structure, given its specific protein composition and coagulation characteristics compared to cow's milk.

To simplify the experimental design and data analysis, certain limitations are introduced in the study. In particular, a limited number of coagulant doses and coagulation temperature regimes are considered without considering additional microbiological or enzymatic factors. Also, emphasis is placed on the study of physicochemical parameters, syneresis, coagulation time, yield, and instrumental textural characteristics without assessing shelf life and organoleptic properties.

4. 2. Production of cheese samples

Fresh whole milk of camel (*Camelus dromedarius*) obtained from a private household located in the local region of Turkestan oblast (Kazakhstan) was used for cheese samples. Chy-Max® M 1000 (Chr. Hansen, Denmark), a purified, standardized liquid chymosin preparation with an activity of 1000 IMCU/ml, produced by submerged fermentation of *Aspergillus niger* var. *awamori* on a plant-based substrate, was used as the coagulant.

The process of soft cheese production from camel milk was realized according to the technological scheme shown in Fig. 1.

Fresh camel milk was filtered and preheated to the specified coagulation-temperatures of 34, 36, 38 and 40°C. The coagulant was added at four concentrations of 0.05, 0.10, 0.15 and 0.20 ml/l, due to the lower coagulation efficiency of camel milk.

After gentle stirring, the milk was kept at the appropriate temperature without stirring until coagulation.

Once the curd was formed, it was cut into cubes of about 2 cm and left for 10-15 minutes to accelerate whey separation. The curd was then gently stirred for 5 minutes and kept at the same temperature for a further 20 minutes. The curd was transferred into molds lined with gauze and left to drain under its own weight at room temperature (20–22°C) for 4 hours.

The cheese samples were then pasteurized in hot whey (85–95°C) for 3–5 minutes, cooled (up to 30 minutes) and salted in 18% NaCl solution (by weight) for 30 minutes. The obtained samples were stored at 4–6°C in 9% saline solution for 30 days.

4. 3. Coagulation time determination

The coagulation time of camel milk under different conditions was determined using a modified method based on the International Dairy Federation standard (IDF 157:2007) [9].

The procedure included preheating raw camel milk to the target coagulation temperatures (34°C, 36°C, 38°C and 40°C) in a water bath with an adjustable thermostat (ELMI TW2.02, Elmi, Latvia). After reaching the target temperature, coagulant was added to the milk in volumes corresponding to the four experimental concentrations (0.05; 0.10; 0.15 and 0.20 ml/l) and stirred for 5 seconds. The flocculation point was measured manually by visual flocculation method. A thin glass rod was lowered into the sample and gently rotated every 10 seconds. The moment of coagulation was considered to be the appearances of the first visible strands of coagulate adhering to the surface of the stick.

4. 4. Syneresis assessment

Syneresis was evaluated based on the volume of whey released from the curd. The curds were transferred into cheese molds lined with cheesecloth and allowed to drain at room temperature for 60 minutes. The separated whey was collected and measured in milliliters, then expressed as a percentage relative to the mass of the initial curd.

4. 5. Moisture content determination

Moisture content of the cheese samples was determined by the oven-drying method in accordance with AOAC (1997), method 926.08[10]. Samples were dried to a constant weight in a forced-air oven at 102 ± 2°C. Moisture content was calculated gravimetrically as the percentage loss in mass after drying.

4. 6. Cheese yield determination

Cheese yield was calculated using the following equation

$$Yield(\%) = \frac{\text{cheese weight}}{\text{milk weight}} \times 100, \quad (1)$$

where "cheese weight" is the weight of the finished cheese (after removing excess whey) and "milk weight" is the weight of raw milk used to produce the sample.

4. 7. Texture profile analysis

Texture profile analysis (TPA) of all cheese samples was performed using a Texture Analyser (TX-700, Stable Micro Systems, France). Testing consisted of two consecutive compression cycles between parallel plates, with a 5-second interval between cycles. A flat cylindrical probe (diameter 25 mm, model TX-CY25H40SS) and a 50 kg load cell were used for the measurements. Test parameters were as follows: pre-test speed, test speed, and post-test speed all set to 5.0 mm/s; compression distance of 4 mm. From the force–time curves, the following texture attributes were calculated: hardness, springiness, cohesiveness, gumminess, chewiness, and resilience.

4. 8. Analysis of experimental data

Statistical analysis was carried out using Microsoft Excel 7.0 (MS Office, USA) and Statistica 6.0 (StatSoft, USA). All results are reported as means ± standard deviations (n = 3). Statistical significance was assessed at the 90% confidence level ($P < 0.10$).

5. Results of development of technology of soft cheese production from camel milk

5. 1. Effect of coagulant dose and coagulation temperature on coagulation time in the soft cheese production from camel milk

The results obtained (Table 1) demonstrate a significant effect of both coagulant dose and coagulation temperature on coagulation time in the soft cheese production from camel milk.

Table 1

Effect of coagulant dose and coagulation temperature on coagulation time, s (mean ± SD, $n = 3$)

Coagulant dose, ml/l	34°C	36°C	38°C	40°C
0.05	289 ± 5.2	184 ± 3.6	136 ± 4.1	77 ± 2.9
0.10	190 ± 4.7	132 ± 2.8	176 ± 3.9	54 ± 2.2
0.15	160 ± 3.4	127 ± 2.6	112 ± 3.1	41 ± 1.8
0.20	132 ± 2.9	94 ± 2.3	79 ± 2.5	39 ± 1.6

The coagulation time of camel milk varied significantly depending on both the coagulant dose and the coagulation temperature. When the coagulant dose was increased from 0.05 to 0.20 ml/l, a pronounced reduction in coagulation time was observed at all temperature regimes investigated. Thus, at 34°C, the coagulation time decreases from 289 ± 5.2 s to 132 ± 2.9 s and at 40°C from 77 ± 2.9 s to 39 ± 1.6 s. This indicates an increase in the proteolytic activity of the ferment as its concentration increases, which in turn accelerates milk coagulation.

A similar trend was observed at other coagulation temperatures: for instance, at 36°C, the coagulation time decreased from 184 ± 3.6 s to 94 ± 2.3 s with an increase in coagulant dose within the same range.

5. 2. Influence of technological parameters on syneresis and yield of soft cheese from camel milk

The syneresis of soft cheese from camel milk varied significantly with coagulant dose and coagulation temperature (Table 2). At the coagulant dose of 0.05 ml/l, increasing the coagulation temperature from 34°C to 40°C resulted in a marked increase in whey separation, with syneresis values increasing from 70.0±1.6% to 90.0±3.0%.

Table 2

Syneresis of soft cheese from camel milk (% relative to 1000 g curd; mean ± SD, $n = 3$)

Coagulant dose, ml/l	34°C	36°C	38°C	40°C
0.05	70.0 ± 1.6	74.0 ± 2.0	78.0 ± 1.8	90.0 ± 3.0
0.10	68.0 ± 1.5	72.0 ± 1.8	76.0 ± 2.1	80.0 ± 2.5
0.15	78.0 ± 1.2	76.0 ± 1.7	76.0 ± 1.8	82.0 ± 1.6
0.20	64.0 ± 1.4	78.0 ± 2.0	72.0 ± 1.6	92.0 ± 1.0

For the coagulant dose of 0.10 ml/l, syneresis ranged from 68.0 ± 1.5% to 76.0 ± 2.1% over the temperature range of 36–38°C, with a maximum value of 80.0 ± 2.5% observed at 40°C. At the coagulant dose of 0.15 ml/l, syneresis values remained stable between 76.0 ± 1.7% and 76.0 ± 1.8% across the same temperature range (36–38°C).

The maximum syneresis (92.0±1.0%) was recorded at 40°C with a coagulant dose of 0.20 ml/l, while the minimum syneresis at this dose (64.0±1.4%) was observed at 34°C.

In general, when the coagulant dose was increased to 0.10–0.15 ml/l and the coagulation temperature was between 34–38°C, the syneresis remained at a relatively moderate level, providing stable whey separation values.

The yield of soft cheese from camel milk was significantly affected by both coagulant dose and coagulation temperature (Table 3).

According to Table 3, the observed values ranged from 104.76 ± 0.12 g to 190.75 ± 0.02 g, emphasizing the critical role of process parameters in regulating the curd extraction efficiency.

Table 3

The yield of soft cheese from camel milk, g (mean ± SD, $n = 3$)

Coagulant dose, ml/l	34°C	36°C	38°C	40°C
0.05	120.70 ± 0.05	123.37 ± 0.08	122.76 ± 0.21	118.63 ± 0.12
0.10	126.36 ± 0.32	132.29 ± 0.18	136.25 ± 0.03	104.76 ± 0.12
0.15	134.44 ± 0.07	134.51 ± 0.05	184.50 ± 0.07	105.01 ± 0.13
0.20	180.52 ± 0.57	138.79 ± 0.09	190.75 ± 0.02	108.73 ± 0.09

At the lowest coagulant dose (0.05 ml/l), cheese yield varied slightly with temperature, increasing slightly from 120.70 ± 0.05 g at 34°C to 123.37 ± 0.08 g at 36°C, before decreasing to 118.63 ± 0.12 g at 40°C.

At 0.10 ml/l of coagulant dose, the cheese yield gradually increased from 126.36 ± 0.32 g at 34°C to a maximum of 136.25 ± 0.03 g at 38°C. However, a marked decrease was observed at 40°C to 104.76 ± 0.12 g.

A similar pattern, though more pronounced, was observed at a dose of 0.15 ml/l. The cheese yield remained relatively stable between 34°C and 36°C, and then increased to 184.50 ± 0.07 g at 38°C, the highest recorded value among all experimental conditions. However, at 40°C, the yield decreased sharply to 105.01 ± 0.13 g, again indicating potential thermal degradation or destabilization of the matrix at elevated temperatures.

At the highest coagulant dose (0.20 ml/l), cheese yield generally increased at lower and moderate temperatures, being 180.52 ± 0.57 g at 34°C and reaching a maximum value of 190.75 ± 0.02 g at 38°C. However, as with the other treatments, the yield was significantly lower at 40°C (108.73 ± 0.09 g).

5. 3. Physicochemical characteristics of soft cheese from camel milk obtained under different technological regimes

Physicochemical parameters of soft cheese from camel milk varied depending on coagulant dose and coagulation temperature (Table 4).

Table 4

Physicochemical parameters of soft cheese from camel milk depending on coagulant dose and coagulation temperature (mean ± SD, $n = 3$)

Temperature (°C)	Dose (ml/l)	Proteins (%)	Fats (%)	Moisture (%)
34	0.05	6.58 ± 0.21	28.85 ± 0.35	59.93 ± 0.45
34	0.10	9.20 ± 0.25	28.63 ± 0.41	60.77 ± 0.51
34	0.15	16.97 ± 0.31	28.31 ± 0.38	60.36 ± 0.38
34	0.20	11.60 ± 0.27	31.28 ± 0.29	60.10 ± 0.29
36	0.05	13.83 ± 0.30	25.54 ± 0.33	56.86 ± 0.52
36	0.10	18.45 ± 0.28	28.08 ± 0.36	59.73 ± 0.46
36	0.15	18.65 ± 0.35	25.69 ± 0.40	60.28 ± 0.33
36	0.20	18.34 ± 0.26	25.11 ± 0.34	63.21 ± 0.27
38	0.05	11.28 ± 0.22	27.78 ± 0.30	56.53 ± 0.41
38	0.10	16.11 ± 0.29	23.62 ± 0.33	59.11 ± 0.36
38	0.15	16.15 ± 0.27	26.59 ± 0.31	60.57 ± 0.48
38	0.20	16.64 ± 0.24	28.07 ± 0.36	60.70 ± 0.42
40	0.05	12.87 ± 0.30	30.22 ± 0.35	60.19 ± 0.39
40	0.10	16.02 ± 0.28	32.15 ± 0.32	57.28 ± 0.34
40	0.15	16.34 ± 0.27	37.48 ± 0.30	45.90 ± 0.51
40	0.20	11.17 ± 0.25	37.60 ± 0.33	49.67 ± 0.29

Protein content generally increased with coagulant dose, reaching a maximum (18.65%) at 36°C and 0.15 ml/l. However, at 40°C, a notable decline (to 11.17%) was observed at the highest dose, suggesting decreased curd retention. At 38°C, protein values remained relatively stable (16.11–16.64%), regardless of dose.

Fat content ranged widely depending on temperature. While relatively stable at 34–36°C (25.11–31.28%), it increased sharply at 40°C with higher doses, reaching 37.60%, indicating enhanced fat retention or moisture loss.

Moisture content was mostly stable at 34°C, but increased with dose at 36°C (from 56.86% to 63.21%). At 38°C, moderate growth was noted. In contrast, at 40°C, moisture sharply declined at higher doses (down to 45.90%), likely due to intensified syneresis at elevated temperature.

5. 4. Textural characteristics of soft cheese from camel milk: hardness, resilience cohesiveness, chewiness and other indicators

Texture profile analysis (TPA) of soft cheese from camel milk revealed significant differences in mechanical properties depending on both coagulant dose and coagulation temperature (Table 5).

The hardness, representing the force required to press the cheese, varied from 15.209 ± 0.348 N to 46.418 ± 0.202 N. At 34°C, increasing the coagulant dose from 0.05 to 0.15 ml/l resulted in a constant increase in hardness (from 15.209 ± 0.348 to 27.190 ± 0.199 N) followed by a decrease of 0.20 ml/l (16.761 ± 0.194 N). At 36°C, maximum hardness was observed at 0.05 ml/l (45.508 ± 1.583 N), with a marked decrease at higher doses.

Cohesiveness, which reflects the internal connectivity of the cheese matrix, varied from 0.222 ± 0.002 to 0.739 ± 0.015. The highest value was recorded at 34°C and 0.15 ml/l dose.

Springiness, which characterizes the ability of the product to recover from deformation, ranged from 0.644 ± 0.003 N to 1.684 ± 0.076 N.

Gumminess and chewiness, which reflect the energy required for chewing, showed similar trends. Maximum gumminess (23.677 ± 0.209 N) were recorded at 36°C and 0.05 ml/l volume and chewiness (21.120 ± 0.742 N) at 34°C and 0.15 ml/l volume.

Resilience, which reflects the degree of cheese recovery after deformation, ranged from 0.128 ± 0.001 to 0.342 ± 0.003. The highest resilience was recorded at 38°C and 0.15 ml/l volume, while the lowest resilience was recorded at 40°C and 0.15 ml/l volume.

5. 5. Development of a technological scheme for producing soft cheese from camel milk

Based on experimental data and analysis of the influence of technological parameters, the technological scheme for the soft cheese production from camel milk was developed (Fig. 1). The scheme includes the main stages of milk processing, coagulation, cutting curd, self-pressing and salting, adapted to take into account the specific properties of camel milk.

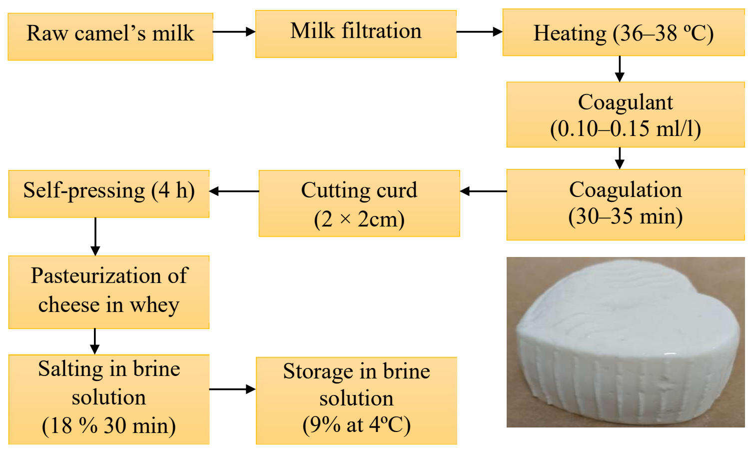

Fig. 1. Scheme of soft cheese from camel milk production

Table 5

Texture profile analysis of soft cheese from camel milk at different coagulant doses and coagulation temperatures (mean ± SD; n = 3)

Temperature (°C)	Dose (ml/l)	Hardness (N)	Cohesiveness	Springiness (N)	Gumminess (N)	Chewiness (N)	Resilience
34	0.05	15.209 ± 0.348	0.423 ± 0.008	0.919 ± 0.015	6.317 ± 0.028	5.993 ± 0.035	0.161 ± 0.002
34	0.10	22.804 ± 0.093	0.393 ± 0.002	0.647 ± 0.009	8.983 ± 0.174	5.784 ± 0.160	0.249 ± 0.005
34	0.15	27,190± 0.199	0.739 ± 0.015	1.043 ± 0.018	20.096 ± 0.128	21.120 ± 0.742	0.149 ± 0.002
34	0.20	16.761 ± 0.194	0.500 ± 0.008	1.684 ± 0.076	8.438 ± 0.140	13.951 ± 0.151	0.178 ± 0.005
36	0.05	45.508 ± 1.583	0.526 ± 0.007	0.864 ± 0.025	23.677 ± 0.209	20.013 ± 0.259	0.269 ± 0.009
36	0.10	26.228 ± 0.344	0.462 ± 0.004	0.728 ± 0.014	12.196 ± 0.159	8.839 ± 0.080	0.292 ± 0.008
36	0.15	31.736 ± 1.001	0.332 ± 0.009	0.728 ± 0.015	10.933 ± 0.085	8.079 ± 0.218	0.176 ± 0.003
36	0.20	20.015 ± 0.498	0.369 ± 0.003	0.739 ± 0.010	7.408 ± 0.120	5.440 ± 0.025	0.215 ± 0.002
38	0.05	46.418 ± 0.202	0.482 ± 0.001	0.804 ± 0.004	22.360 ±0.197	17.967 ± 0.133	0.253 ± 0.003
38	0.10	25.102 ± 0.145	0.394 ± 0.003	0.656 ± 0.007	5.948 ± 0.065	3.899 ± 0.030	0.242 ± 0.002
38	0.15	28.282 ± 0.249	0.505 ± 0.005	0.782 ± 0.002	9.224 ± 0.033	7.209 ± 0.023	0.342 ± 0.003
38	0.20	22.285 ± 0.147	0.417 ± 0.002	0.644 ± 0.003	9.284 ± 0.084	5.980 ± 0.033	0.302 ± 0.001
40	0.05	22.962 ± 0.179	0.330 ± 0.004	0.687 ± 0.007	7.580 ± 0.050	5.209 ± 0.036	0.172 ± 0.002
40	0.10	15.226 ± 0.081	0.343 ± 0.001	0.687 ± 0.004	5.216 ± 0.033	3.584 ± 0.034	0.159 ± 0.001
40	0.15	19.569 ± 0.272	0.222 ± 0.002	0.751 ± 0.005	6.573 ± 0.041	4.936 ±0.033	0.128 ± 0.001
40	0.20	17.580 ± 0.081	0.327 ± 0.004	0.665 ± 0.006	5.742 ± 0.007	3.817 ± 0.022	0.157 ± 0.001

The developed scheme can be used in technological process and adaptation of the technology for industrial soft cheese production from camel milk.

6. Discussion of the results of development of technology for soft cheese production from camel milk

The results of the present study show that both coagulant dose and coagulation temperature have significant and interdependent effects on syneresis, yield, and moisture content and textural properties of soft cheese from camel milk. These results are particularly important for optimizing the rational use of camel milk in cheese production, a niche but increasingly important industry in arid and semi-arid regions.

Analysis of the data (Table 1) showed that, for all investigated coagulant doses, coagulation time decreased with increasing temperature. For example, at the minimum coagulant dose of 0.05 ml/l, the coagulation time decreased from 289 ± 5.2 s at 34°C to 77 ± 2.9 s at 40°C. Thus, the coagulation time was reduced by 212 s (289 – 77 = 212) at 40°C compared to 34°C. A similar trend was observed at higher coagulant doses, with a minimum coagulation time of 39 ± 1.6 s recorded at 0.20 ml/l and 40°C. This value corresponds to the shortest coagulation time observed across all experimental conditions.

Increasing the temperature consistently led to a marked reduction in coagulation time at all coagulant doses. This observation aligns with previous studies indicating that elevated temperatures enhance enzymatic activity and reduce casein micelle stability, thereby accelerating casein aggregation and curd formation [11, 12].

In addition, at each fixed temperature, an increase in coagulant dose from 0.05 to 0.20 ml/l consistently resulted in a shorter coagulation time. For example, at 36°C, the coagulation time decreased from 184 ± 3.6 s (0.05 ml/l) to 94 ± 2.3 s (0.20 ml/l). This inverse correlation between coagulant dose and coagulation time is consistent with the enzymatic kinetics of milk coagulation, where a higher concentration of enzyme accelerates the hydrolysis of ϰ-casein, promoting faster curd formation [13, 14].

The syneresis values (Table 2) varied with the combination of temperature and coagulant dose. Thus, at a coagulant dose of 0.05 ml/l, increasing the temperature from 34°C to 40°C resulted in an increase in whey separation from 70.0±1.6% to 90.0±3.0%. Notably, the lowest syneresis value for this dose (74.0 ± 2.0%) was observed at 36°C, suggesting that moderate temperatures may promote gel formation with improved moisture-retention capacity.

The most pronounced syneresis (92.0±1.0%) was recorded at 40°C and a coagulant dose of 0.20 ml/l, which is likely due to the formation of an excessively dense and dry protein matrix that retains less moisture. Conversely, the lowest syneresis for this dose (64.0±1.4%) was observed at 34°C, indicating that lower temperatures may partially mitigate the moisture loss caused by the high coagulant dose.

The cheese yield data indicate a nonlinear relationship between coagulant dose and coagulation temperature. Moderate coagulant doses (0.10–0.15 ml/l) at 36–38°C (Table 3) were found to optimize the balance between curd firmness and moisture retention, thereby enhancing yield. In contrast, both insufficient and excessive coagulant doses at suboptimal temperatures (particularly at 40°C) resulted in incomplete curd formation or curd structural degradation, ultimately reducing product recovery. These findings are consistent with previous research showing that excessive rennet activity or elevated coagulation temperatures can lead to over-hydrolysis of ϰ-casein, curd fragility, and diminished whey retention capacity [15].

The cheese yield in the present study (184.50 ± 0.07 g at 38°C and 0.15 ml/l coagulant dose) was significantly higher compared to previously published data [16, 17].

These differences appear to be due to variation in temperature, coagulant dose and the use of starter culture, which confirms the critical importance of optimizing rennet coagulation parameters to improve coagulation efficiency and increase product yield. This can be explained by the efficient proteolysis of ϰ-casein, which promotes the formation of a strong gel structure with high fat and moisture retention.

However, increasing the temperature to 40°C led to a marked decline in yield, even at higher coagulant doses. For example, at 0.15 and 0.20 ml/l, yields dropped to 105.01 ± 0.13 g and 108.73 ± 0.09 g, respectively. This decrease is likely due to excessive enzymatic activity resulting in a fragile and overly compact curd structure, which promotes syneresis and limits moisture retention.

These results are in agreement with literature data, according to which the coagulation temperature of camel milk should be lower than 40°C to avoid excessive proteolysis and weakening of the curd structure [17].

The physicochemical properties of soft cheese from camel milk were significantly influenced by both coagulation temperature and coagulant dose (Table 4). Protein content analysis revealed that optimum protein values (up to 18.65%) were observed at 36°C and 0.15 ml/l coagulant dose, reflecting effective protein retention under optimal coagulation conditions. These results are comparable to, or slightly higher than, those reported in previous studies [2].

The fat content also showed different dynamics depending on the process parameters. At low temperature (34 °C), the fat content remained high and stable (28.31–31.28 %), whereas at higher temperatures (40 °C) and coagulant doses of (0.15–0.20 ml/l), maximum values (37.48–37.60%) were observed. This may indicate a better incorporation of fat into the coagulated matrix at accelerated coagulation, but also a possible dryness of the product, accompanied by a decrease in water-holding capacity.

At 36–38°C, the fat content depended on the coagulant dose: at 36°C, it ranged from 28.08% to 25.69% (for 0.10 and 0.15 ml/l, respectively), while at 38°C, it ranged from 23.62% to 26.59%. These values are within the typical range reported for soft cheese from camel milk and are comparable to the results of [2], for dry- and brine-salted variants, respectively.

Moisture content remained relatively stable at 34°C (59.93 ± 0.45% to 60.77 ± 0.51%) with increasing coagulant dose from 0.05 to 0.20 ml/l, indicating little effect of enzymatic activity at low temperatures on the degree of curd dehydration. At 36°C, the effect of coagulant dose became more obvious. The moisture content gradually increased from 56.86 ± 0.52% (0.05 ml/l) to 63.21±0.27% (0.20 ml/l), indicating a positive correlation between coagulant dose and moisture retention. This may be due to the formation of thinner protein networks that retain more moisture during gel formation at moderately elevated temperatures. Similar behavior was described by [18], where higher coagulation temperatures improved water retention in white cheese gel.

At 38°C, an increase in moisture content with increasing coagulant dose was also observed, but the changes were less pronounced (from 56.53 ± 0.41% to 60.70 ± 0.42%), which may indicate that the ultimate efficiency of the coagulation process was reached in this temperature range.

On the contrary, at 40°C, a significant decrease in moisture content was observed with increasing coagulant dose. The moisture content decreased sharply from 60.19 ± 0.39% at 0.05 ml/l to 45.90 ± 0.51% and 49.67 ± 0.29% at 0.15 and 0.20 ml/l, respectively. This reverse trend may be attributed to rapid coagulant doses, resulting in drier curd. These results are in agreement with previous studies indicating that excessive coagulant dose and elevated temperatures lead to the formation of denser protein networks with reduced moisture retention capacity [12].

Texture profiling further confirmed these trends (Table 5). Samples made at 36–38°C using 0.10–0.15 ml/l coagulant showed optimal hardness, cohesiveness, resilience and chewiness, indicating a balanced and consumer acceptable consistency. In contrast, samples obtained at 34°C showed weaker gels, while samples obtained at 40°C were structurally unstable and mechanically brittle.

Interestingly, the highest overall hardness value (46.418 ± 0.202 N) was recorded at 38°C and 0.05 ml/l volume, which may be due to the lower moisture content resulting in a denser protein network. This trend confirms the inverse correlation between moisture content and hardness, which is in agreement with data published in the literature [19].

These results indicate a synergistic effect of coagulant dose and thermal conditions in which moderate enzymatic activity combined with optimized thermal coagulation results in a well-developed, moisture-retaining gel structure. Such conditions not only increase the technological yield but also improve the texture and stability of the final product.

Despite the promising results achieved with the proposed coagulant doses and coagulation temperatures for soft cheese production from camel milk, several limitations of the study should be acknowledged. The experiments were conducted under controlled laboratory conditions using raw camel milk from a single source, without accounting for seasonal, breed-specific, or dietary variations that may affect milk composition and coagulation behavior. Moreover, only one commercial coagulant was tested, which may limit the generalizability of the findings. The study also focused primarily on physicochemical properties, coagulation parameters, cheese yield, and instrumental texture, while important aspects such as microbiological safety, shelf life, and sensory attributes were not evaluated. These limitations restrict the immediate applicability of the results to industrial-scale production and real-world processing conditions.

Future research should address these gaps by testing a wider range of coagulants and processing parameters, examining the effects of milk origin and storage conditions, and incorporating microbial, sensory, and ripening characteristics into the evaluation. These efforts are essential to confirm the practical relevance and technological applicability of the proposed approach for broader use in the dairy industry.

7. Conclusions

1. Both coagulant concentration and coagulation temperature significantly influenced coagulation time. Increasing the coagulant dose from 0.05 to 0.20 ml/l consistently reduced gelation time, particularly at 40°C, indicating enhanced proteolytic activity and accelerated coagulation – critical for forming a dense, stable curd.

2. The level of syneresis in soft cheese from camel milk increased with higher coagulation temperatures and coagulant doses. However, optimal outcomes-moderate syneresis and maximum yield – were achieved with 0.10–0.15 ml/l coagulant at 36–38°C. These conditions promoted an optimal balance between whey expulsion and moisture/fat retention, resulting in yields of up to 184.50 ± 0.07 g.

3. The physicochemical properties of the cheeses varied significantly with coagulation parameters. It was found that the combination of 36–38°C and 0.10–0.15 ml/l coagulant dose led to improved retention of protein and moisture, supporting the production of high-quality soft cheese from camel milk.

4. The most desirable textural parameters – hardness, cohesiveness, resilience, and chewiness – were observed under the same optimal conditions (36–38°C, 0.10–0.15 ml/l). These values reflect a firm, elastic, and well-balanced cheese matrix suitable for soft cheese varieties. In contrast, excessive coagulant dose or higher coagulation temperatures (e.g., 40°C) negatively affected textural integrity, reducing cohesiveness and chewiness.

5. A technological scheme for soft cheese production from camel milk was developed, including the stages of pasteurization, enzymatic coagulation under optimal conditions (0.10–0.15 ml/l at 36–38°C), cutting curd, self-pressing, and salting. The application of this scheme ensures stable product quality, high yield, and favorable sensory and textural attributes, demonstrating its suitability for industrial-scale cheese production.

Conflict of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, copyright or any other that could affect the study and the results presented in this article.

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Data availability

All data is available in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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