Study on the Possibility of Using Camel Milk (*Camelus dromedarius*) and Lemon Juice as a Natural Acid Coagulant in Soft Cheese Production

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Abstract

This study evaluated graded doses of lemon juice as a natural acid coagulant for soft cheese made from camel milk (*Camelus dromedarius*), with commercial rennet and crude ginger extract included as reference coagulants. Thirty-three litres of fresh milk were allocated to 11 treatments with three replicates of 1 L each in a completely randomised design: eight lemon-juice doses (T1–T8: 150–500 mL/L milk), milk without coagulant (C1), commercial rennet (C2) and crude ginger extract (C3). Because the three coagulant types require different temperatures, pH values and holding times, the reference treatments were manufactured under their own protocols and are reported descriptively rather than as a like-for-like comparison with the lemon-juice series. Data were analysed by one-way ANOVA with least significant difference (LSD) at $P < 0.05$, and Pearson correlation with dose was calculated for T1–T8. Within the lemon-juice series, cheese yield increased from 9.36% (T1) to 24.06% (T8), titratable acidity rose from 0.43 to 0.75% and pH fell from 5.65 to 4.65, all strongly correlated with dose (r = 0.95, 0.98 and −0.99). Protein increased from 8.30 to 12.84% and ash decreased from 2.71 to 2.53% (r = 0.93 and −0.97), fat peaked at 15.79% in T6 (400 mL/L), and moisture increased significantly only at the two highest doses (60.31% in T8). Sensory evaluation by 40 assessors on a nine-point hedonic scale showed significant differences among T1–T8 for all seven attributes; T8 scored highest, but its mean overall acceptability (3.18 ± 0.74) remained below the neutral point of 5. Lemon juice within 150–500 mL/L is therefore a technically workable acid coagulant for camel-milk soft cheese in terms of yield and composition; however, because all sensory scores remained below the neutral point, the process in its current form cannot be recommended for commercial production, and reduction of the juice volume added, flavour development and storage stability require further work.

Keywords: camel milk; lemon juice; acid coagulation; soft cheese; cheese yield; sensory evaluation.

Introduction

Camel milk (*Camelus dromedarius*) is an important food resource in arid and semi-arid regions [3], yet its conversion into coagulated dairy products, particularly cheese, faces technological challenges related to the composition of its proteins and the structure of its casein micelles. Recent reviews confirm that camel milk differs from bovine milk in its casein-to-whey-protein ratio, its micelle structure and its proportion of κ-casein, factors that contribute to slow coagulation and the formation of a relatively weaker curd; cheese-making from camel milk therefore requires modification of the processing conditions compared with the conventional techniques used for bovine milk [3,4,15]. The low κ-casein content (about 3.5% of total casein compared with about 13% in bovine milk), the larger micelles and the high proportion of β-casein are the main structural reasons for this behaviour [5,7]. The type of coagulant and the processing conditions consequently affect the yield,

ISSN 2072-3857

structure and final properties of the cheese [3,4,15].

Cheese-making traditionally relies on enzymatic coagulation with rennet or on direct acidification or fermentation, and research has turned to alternative coagulants of plant or acid origin. Acid coagulation is of particular importance for camel milk: lowering the pH reduces the electrostatic repulsion between casein micelles and dissolves part of the colloidal calcium phosphate, which helps the proteins to aggregate and form a curd [14]. Mbye *et al*. [15] showed that camel-milk cheese can be produced by direct acidification with organic acids, with higher moisture and lower curd firmness than cheese produced by chymosin coagulation; in a direct comparison of camel and bovine soft cheeses made with chymosin, citric acid or acetic acid, camel-milk cheeses were softer, with a smooth, continuous casein network, and panellists preferred the cheeses made with citric acid [16]. Studies using recombinant camel chymosin have also demonstrated the possibility of forming soft cheese from camel milk, with yield and composition affected by the manufacturing system [1]; pre-acidification with citric acid can influence cheese properties [12], and the pH of camel milk at the moment of coagulation has been shown to depend on temperature and acidification rate [13].

Lemon juice is a natural source of organic acids and can act as an acid coagulant by lowering the pH of milk to the range in which casein micelles become less stable. Mihretie *et al*. [17] studied the addition of 150–500 mL of lemon juice per litre of camel milk at ambient temperature and reported an increase in cheese yield with increasing addition, together with changes in moisture, protein and some sensory attributes. Acidification with citric acid is likewise capable of forming a soft camel cheese with higher moisture than enzymatic coagulation [15]. Evaluating lemon juice under the conditions of local camel milk therefore provides a basis for developing a natural acid coagulant for soft-cheese manufacture, the response being related to milk composition and processing conditions; comparison with previous studies also helps to explain differences in absolute values arising from differences in milk source, temperature, pH and coagulation time.

Ginger (*Zingiber officinale*), by contrast, represents a plant enzymatic coagulant with a different mechanism: its rhizomes contain proteases capable of hydrolysing caseins, and Huang *et al*. [9] showed that ginger proteases possess milk-clotting activity with a tendency to hydrolyse κ-casein selectively. In camel milk, Hailu *et al*. [8] found that the highest clotting activity of crude ginger extract was obtained at pH 5.0, 65 °C and a concentration of 10% (v/v), while Fguiri *et al*. [6] reported that the optimum conditions differ according to the method of enzyme extraction; other plant extracts, such as green carob, have recently been optimised as coagulants for soft camel cheese [18]. Because enzymatic and acid coagulants act through different mechanisms and require different temperatures, pH values and holding times, rennet and ginger extract were included in the present study as reference treatments processed under their own conditions, not as controls manufactured identically to the lemon-juice cheeses.

On this basis, the present study aimed to evaluate the effect of different concentrations of lemon juice on the yield, acidity, pH, chemical composition and sensory attributes of soft cheese made from camel milk, to quantify the dose–response relationship within the range 150–500 mL/L, and to describe the performance of commercial rennet and crude ginger extract as reference coagulants.

Hypothesis. Increasing the concentration of lemon juice produces dose-dependent changes in the acidity, pH, yield, chemical composition and sensory attributes of the cheese as a result of changes in the intensity of acidification, the aggregation of milk proteins and the retention of curd constituents. The performance of lemon juice is also expected to differ from that of commercial rennet and ginger extract because of the different coagulation mechanisms and processing conditions.

Materials and Methods

Location of the study

The study was conducted at Al-Ameen Laboratory, Najaf, Iraq.

Raw materials and experimental design

Thirty-three litres of fresh camel milk from a local breed were used, collected during the spring season from the farm of [university of kufa] and transported in coolers at 4 °C within one hour of milking. The raw milk was filtered through sterile cloth on arrival, and its pH and titratable acidity were determined before processing using the methods described under "Chemical and physical analyses" (values are reported under Results). The milk was distributed among 11 treatments with three replicates each, one litre per experimental unit, in a completely randomised design. The treatments comprised eight doses of fresh, undiluted lemon juice (T1–T8: 150–500 mL/L), a milk-only treatment without coagulant (C1), a commercial-rennet treatment (C2) and a crude ginger-extract treatment (C3). The milk-only treatment (C1) was included as a negative control to quantify the material recovered by the heat treatment alone (heating to boiling without any coagulant), so that the contribution of lemon-juice acidification to curd formation, yield and composition could be separated from the effect of heating. Table 1 summarises the coding of the treatments together with the temperature, pH and holding time applied to each.

ISSN 2072-3857

Table 1. Coding of the experimental treatments and the manufacturing conditions applied to each coagulant

Post-coagulation handling	pH adjustment / pH at coagulation	Coagulation temperature and holding time	Milk pre-treatment	Coagulant and dose	Code
Whey drained 15 min through cloth; 4 h at 4 °C	None (natural milk pH)	Heated to boiling and held 10 min (same heating step as T1–T8)	72 °C for 5 min	None (milk only, control)	C1
Whey drained 15 min through cloth; 4 h at 4 °C	None (natural milk pH)	Renneting at [35] °C for [30] min (temperature and clotting time recommended by the manufacturer)	72 °C for 5 min, then cooled	Commercial animal rennet (strength 1:10,000), 0.02 g/L	C2
Whey drained 15 min through cloth; 4 h at 4 °C	Milk adjusted to pH 5.0 with 0.1 M citric acid before addition of extract	65 °C for 30 min	72 °C for 5 min, then cooled to 65 °C	Crude ginger extract (1:2 w/v), 100 mL/L	C3
Whey drained 15 min through cloth; 4 h at 4 °C	No separate adjustment; pH set by the juice dose (pH of the resulting cheese: Table 2)	Juice added at 72 °C; heating continued to boiling and held 10 min; curd recovered at the end of this period	72 °C for 5 min	Fresh lemon juice at 150, 200, 250, 300, 350, 400, 450 and 500 mL/L milk (T1–T8, respectively)	T1–T8

The three coagulant types were processed under the temperature, pH and time each requires; C2 and C3 are therefore reference treatments, not controls manufactured identically to T1–T8 (see Section “Comparability of the treatments”).

ISSN 2072-3857

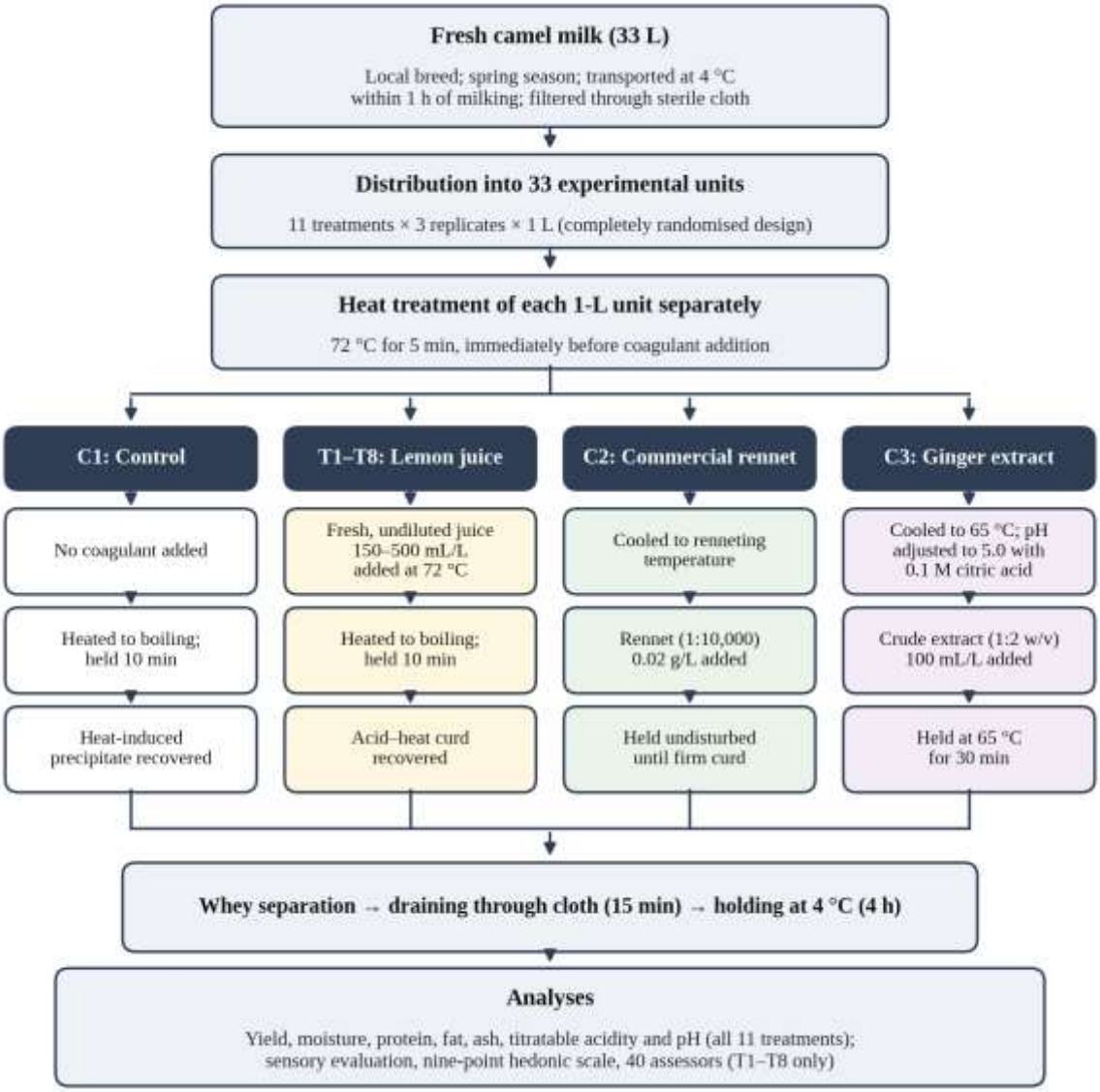


Figure 1. Flow diagram of soft-cheese manufacture from camel milk: control without coagulant (C1), lemon-juice treatments (T1–T8), commercial rennet (C2) and crude ginger extract (C3). Each 1-L experimental unit was processed separately from the heat-treatment step onwards.

Preparation of the coagulants

Fresh lemons were squeezed by hand and the juice filtered through sterile cotton cloth; the juice was used fresh and undiluted. Its titratable acidity was determined by volumetric titration against 0.1 N NaOH and expressed as citric acid (%) [2] (the value is reported under Results), and the juice was stored in dark glass bottles at 4 °C and used within 24 h. Crude ginger extract was prepared by grinding fresh rhizomes with distilled water at a ratio of 1:2 (w/v), leaving the mixture for one hour at room temperature, filtering and centrifuging at 4,000 rpm for 15 min, and using the clear supernatant directly. Because extraction at room temperature for one hour may cause partial loss of protease activity through autolysis, extraction in a cold medium (4 °C) is preferable; this limitation is taken into account when interpreting the results of C3. Commercial animal rennet (strength 1:10,000) was dissolved in a small volume of distilled water immediately before use.

ISSN 2072-3857

Cheese manufacture

Cheese was manufactured according to the scheme in Figure 1 and the conditions in Table 1. The milk was not heat-treated as a single batch: after distribution, each 1-L experimental unit was heat-treated separately in its own vessel at 72 °C for 5 min immediately before the coagulant was added, so that all units received the same heat load and the lemon juice was added to milk at the specified temperature. In the lemon-juice treatments the specified volume of juice (150–500 mL/L) was added to the hot milk and heating was continued to boiling, where the mixture was held for 10 min; curd formation began within this period and the curd was recovered at the end of the 10 min. In the ginger treatment the heat-treated milk was cooled to 65 °C, its pH was adjusted to 5.0 with 0.1 M citric acid, the crude extract was added at 100 mL/L and the milk was held at 65 °C for 30 min, the optimum reported for ginger proteases in camel milk [8]. In the rennet treatment the milk was cooled to the renneting temperature recommended by the manufacturer [35] °C), rennet was added at 0.02 g/L and the milk was left undisturbed for [30] min, until a firm curd had formed. The control (C1) followed the same heating and holding steps as the lemon-juice series without any coagulant. After curd formation the whey was separated, the curd was drained for 15 min through a piece of cloth, then cooled and held for 4 h at 4 °C before analysis and sensory evaluation. The product is a fresh, unripened soft cheese intended for consumption shortly after manufacture; the 4 h holding period at 4 °C was chosen to complete whey drainage, cooling and firming of the curd and to characterise the cheese in the fresh state in which it would be consumed. A longer holding period (e.g. 24 h) could allow further whey expulsion and flavour stabilisation, and its effect is proposed for future work.

Comparability of the treatments

The three coagulants act by different mechanisms and cannot be applied under identical conditions: acid coagulation with lemon juice was carried out at boiling temperature for 10 min, enzymatic coagulation with ginger extract at pH 5.0 and 65 °C for 30 min, and rennet coagulation at the mild temperature and near-neutral pH the enzyme requires. Differences among C2, C3 and the lemon-juice cheeses therefore reflect the combined effect of coagulant type and processing conditions and should not be attributed to the coagulant alone. For this reason the statistical dose–response analysis is confined to T1–T8, and the results of C1–C3 are presented alongside them for descriptive reference only.

Chemical and physical analyses

The weight of cheese produced from each experimental unit was recorded and the yield calculated as: Yield (%) = (weight of cheese produced ÷ weight of milk used) × 100. Note: the weight of milk refers to the camel milk alone (1 L per experimental unit) and excludes the lemon juice, rennet solution or ginger extract added; yield is therefore expressed per unit of milk processed, so that all treatments are compared on the same raw-material basis. Expressed on the total mass of the milk–coagulant mixture, the yields of the lemon-juice treatments would be proportionally lower (by about one third in T8). Moisture, protein, fat and ash were determined according to standard AOAC methods [2]; all compositional results are expressed on a wet (as-is) basis, and the residual fraction (carbohydrate and other constituents not determined individually) was calculated by difference as 100 − (moisture + protein + fat + ash). Titratable acidity was determined by volumetric titration against 0.1 N NaOH and expressed as a percentage of lactic acid [2]. pH was measured in the drained cheese with a pH meter calibrated with standard buffer solutions, the reading

ISSN 2072-3857

being recorded after stabilisation at the measurement temperature. All determinations were made in triplicate on each experimental unit.

Sensory evaluation

Sensory evaluation was restricted to the eight lemon-juice cheeses (T1–T8), which constituted the experimental factor under study; the control and reference cheeses (C1–C3) were manufactured under different conditions and were not presented to the panel. Forty assessors from among the teaching staff and students of the Department of Food Sciences took part; they had previous experience of participating in the evaluation of food products in applied research within the Department but had not been formally trained as a specialised sensory panel. Each assessor evaluated all eight samples in a single session after the 4 h holding period at 4 °C. Samples were presented in white cups coded with random three-digit numbers and served in a randomised order, and lukewarm water was provided for rinsing the mouth between samples. A nine-point hedonic scale was used (1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely) to rate the degree of liking of seven attributes: softness, acidity, colour, odour, flavour, appearance and overall acceptability. The organisation of the test followed the principles of ISO 22935 [10,11]. For each attribute the 40 scores per treatment were treated as replicates in the analysis described below; because the scale midpoint (5) denotes neither like nor dislike, absolute acceptability was judged against this midpoint and not only by the ranking of the treatments.

Statistical analysis

Chemical and physical data (three replicates × 11 treatments) were subjected to to one-way analysis of variance (ANOVA) in a completely randomised design (error df = 22). Sensory scores (40 assessors × 8 treatments) were analysed by one-way ANOVA with treatment as the factor (error df = 312). Where the F-test was significant, means were separated by the least significant difference (LSD) test at $P < 0.05$, computed from the pooled within-treatment variance; the LSD value is given beneath each table and means sharing a letter within a column do not differ significantly. Results are presented as mean ± standard deviation (SD). The dose–response trend within the lemon-juice series was described by Pearson's correlation coefficient between lemon-juice dose (150–500 mL/L) and the treatment mean of each response variable (n = 8, df = 6). Because C1–C3 were processed under different conditions, the ANOVA across all 11 treatments tests differences among the treatments as manufactured and does not isolate the effect of coagulant type; inferences on dose–response are therefore confined to T1–T8. The statistical procedures followed Steel and Torrie [20], and the analyses were performed with GenStat (Version 22).

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Results and Discussion

Table 2. Effect of the coagulation treatments on cheese yield, titratable acidity and pH (mean ± SD, n = 3)

pH	Titratable acidity (%)	Yield (%)	Treatment
6.48 ± 0.02 [a]	0.33 ± 0.01 [i]	6.92	C1
6.32 ± 0.01 [b]	0.35 ± 0.01 [i]	10.63	C2
5.80 ± 0.02 [c]	0.38 ± 0.01 [h]	11.51	C3
5.65 ± 0.01 [d]	0.43 ± 0.02 [g]	9.36	T1
5.48 ± 0.02 [e]	0.52 ± 0.02 [f]	10.87	T2
5.30 ± 0.01 [f]	0.56 ± 0.01 [e]	10.35	T3
5.15 ± 0.02 [g]	0.57 ± 0.01 [e]	11.14	T4
5.12 ± 0.02 [h]	0.60 ± 0.01 [d]	15.82	T5
4.98 ± 0.01 [i]	0.65 ± 0.01 [c]	17.51	T6
4.80 ± 0.02 [j]	0.71 ± 0.02 [b]	23.10	T7
4.65 ± 0.01 [k]	0.75 ± 0.01 [a]	24.06	T8
0.03	0.02	–	LSD (0.05)
–0.99***	0.98***	0.95***	r (dose)

Means within a column followed by different superscript letters differ significantly ($P < 0.05$; LSD). Yield is reported as the mean of three replicates; replicate values were not recorded for yield, so SD and mean separation are not available for this variable. r = Pearson correlation between lemon-juice dose and treatment mean across T1–T8 (n = 8); *** $P < 0.001$. Treatment codes: C1 = milk only (control, no coagulant); C2 = commercial rennet; C3 = crude ginger extract (100 mL/L); T1–T8 = 150, 200, 250, 300, 350, 400, 450 and 500 mL lemon juice per litre of milk, respectively. C1–C3 were processed under different conditions from T1–T8 (Table 1) and are shown for descriptive reference.

Table 3. Chemical composition (wet basis) of the soft cheese produced from camel milk with lemon juice (T1–T8), without coagulant (C1), with commercial rennet (C2) and with crude ginger extract (C3) (mean ± SD, n = 3)

Residual by difference (%)	Ash (%)	Fat (%)	Protein (%)	Moisture (%)	Treatment
23.03	2.83 ± 0.01 ^{a}	10.51 ± 0.01 ^{j}	7.40 ± 0.01 ^{j}	56.23 ± 0.01 ^{f}	C1
20.08	2.73 ± 0.01 ^{c}	11.42 ± 0.01 ^{i}	9.15 ± 0.02 ^{h}	56.62 ± 0.01 ^{de}	C2
21.47	2.78 ± 0.01 ^{b}	10.51 ± 0.01 ^{j}	10.10 ± 0.01 ^{f}	55.14 ± 0.02 ^{g}	C3
19.81	2.71 ± 0.01 ^{d}	12.46 ± 0.01 ^{h}	8.30 ± 0.03 ^{i}	56.72 ± 0.01 ^{cde}	T1
18.03	2.66 ± 0.01 ^{e}	13.12 ± 0.03 ^{g}	9.44 ± 0.02 ^{g}	56.75 ± 0.01 ^{cd}	T2
15.64	2.65 ± 0.01 ^{e}	14.26 ± 0.02 ^{f}	10.74 ± 0.01 ^{e}	56.71 ± 0.01 ^{cde}	T3
14.09	2.60 ± 0.01 ^{g}	14.97 ± 0.02 ^{d}	11.53 ± 0.01 ^{d}	56.81 ± 0.01 ^{cd}	T4
13.55	2.62 ± 0.01 ^{f}	14.74 ± 0.01 ^{e}	12.19 ± 0.04 ^{b}	56.90 ± 0.01 ^{c}	T5
13.00	2.55 ± 0.01 ^{h}	15.79 ± 0.02 ^{a}	12.14 ± 0.03 ^{c}	56.52 ± 0.03 ^{e}	T6
12.30	2.55 ± 0.01 ^{h}	15.59 ± 0.02 ^{c}	12.17 ± 0.02 ^{bc}	57.39 ± 0.41 ^{b}	T7
8.68	2.53 ± 0.01 ^{i}	15.64 ± 0.04 ^{b}	12.84 ± 0.05 ^{a}	60.31 ± 0.04 ^{a}	T8
	0.02	0.04	0.04	0.21	LSD (0.05)
	−0.97***	0.93***	0.93***	0.65 ^{ns}	r (dose)

Means within a column followed by different superscript letters differ significantly ($P < 0.05$; LSD). r = Pearson correlation between lemon-juice dose and treatment mean across T1–T8 (n = 8); *** $P < 0.001$; ns = not significant ($P = 0.08$). Values are expressed on a wet (as-is) basis. Residual = 100 − (moisture + protein + fat + ash), comprising carbohydrate (mainly lactose and, in T1–T8, sugars and organic acids from the lemon juice) and constituents not determined individually. Because the variability among analytical replicates was very small (SD mostly 0.01–0.05), the LSD values are small and differences of a few hundredths of a percentage point are statistically significant. Treatment codes: C1 = milk only (control, no coagulant); C2 = commercial rennet; C3 = crude ginger extract (100 mL/L); T1–T8 = 150, 200, 250, 300, 350, 400, 450 and 500 mL lemon juice per litre of camel milk, respectively. C1–C3 were processed under different conditions from T1–T8 (Table 1) and are shown for descriptive reference.

Cheese yield, titratable acidity and pH

Cheese yield, titratable acidity and pH varied markedly among the treatments, with a consistent trend towards higher yield and acidity and lower pH as the dose of lemon juice increased (Table 2; Figure 2). ANOVA indicated highly significant treatment effects on acidity and pH ($P < 0.001$). Within the lemon-juice series, yield rose from 9.36% in T1 to 24.06% in T8, titratable acidity from 0.43 to 0.75% and pH fell from 5.65 to 4.65; across T1–T8, yield, acidity and pH were all strongly correlated with dose (r = 0.95, 0.98 and −0.99, respectively; $P < 0.001$). Acidity differed significantly between successive doses except between T3 and T4 (0.56 and 0.57%), whereas pH differed significantly between every pair of treatments except T4 and T5 (5.15 and 5.12), so the acidification response was essentially continuous over the range studied. Yield changed little between 150 and 300 mL/L (9.36–11.14%)

ISSN 2072-3857

and then rose steeply from 350 mL/L onwards. One possible explanation is that the lower doses did not supply enough acid for extensive aggregation of casein and whey proteins under the conditions used; this interpretation remains tentative, however, because pH differed little between T4 and T5 (5.15 and 5.12) while yield increased from 11.14 to 15.82%, and clotting time and whey composition were not measured. Factors other than pH, such as the total amount of acid added and the extent of whey-protein co-precipitation during boiling, are therefore also likely to contribute.

The raw camel milk had a pH of 6.48 and a titratable acidity 0.33% (as lactic acid), and the fresh lemon juice used had a titratable acidity of 0.75% (as citric acid). Lemon juice is a concentrated source of citric acid, containing about 48 g/L [19]; at this level, the doses of 150–500 mL/L would supply roughly 7–24 g of citric acid per litre of milk. The progressive increase in the amount of acid added therefore accounts for the continuous rise in the titratable acidity of the cheese (0.43–0.75%) and the corresponding fall in pH (5.65–4.65), and the part of this acid retained in the curd contributes to its sour taste (see "Sensory evaluation").

These trends are consistent with Mihretie *et al*. [17], who used the same range of addition (150–500 mL/L) and reported increasing yield and acidity with increasing lemon juice, although their coagulation was carried out at ambient temperature over a prolonged period, whereas the present protocol combined acidification with boiling for 10 min; absolute values are therefore not directly comparable between the two studies. The agreement in trend nevertheless indicates that increasing acid addition is associated with a change in the behaviour of the milk proteins, the formation of the curd and the retention of part of the water and some solids. Mbye *et al*. [15] also showed that the yield and moisture of camel-milk cheese are affected by the type of acid and the processing conditions; the maximum yield obtained here (24.06%) is close to the optimised yield of 24.1% reported for soft camel cheese coagulated with green carob extract [18], and is well above the yield of the rennet reference in the present study (10.63%).

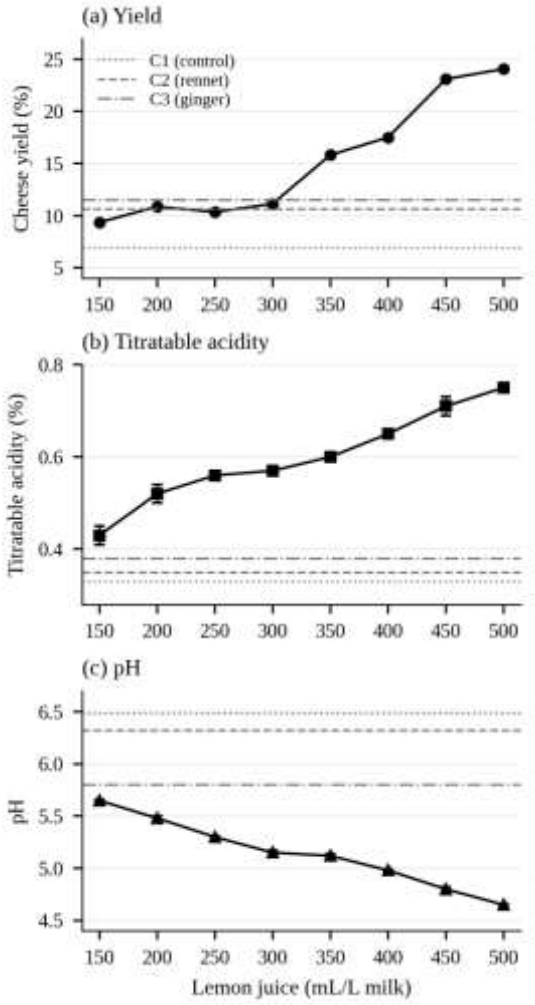


Figure 2. Effect of lemon-juice dose on (a) cheese yield, (b) titratable acidity and (c) pH of camel-milk soft cheese (T1–T8, which involved the addition of different proportions of lemon juice; mean ± SD, n = 3). Horizontal lines show the control (C1), rennet (C2) and ginger-extract (C3) reference treatments, which were processed under different conditions (Table 1).

ISSN 2072-3857

The increase in yield with increasing acid addition can be explained by the greater destabilisation of the casein micelles and aggregation of the protein as pH falls, together with greater retention of water and some solids within the curd; at the pH values reached in the higher lemon-juice treatments (4.65–5.15), which approach the isoelectric point of casein, colloidal calcium phosphate is largely solubilised and the micelles aggregate into an acid gel that entraps water and fat [14]. The combination of acidification with heating to boiling also denatures the whey proteins and allows them to co-precipitate with the caseins, which contributes to the high yields at the upper doses and distinguishes these cheeses from the acid-set cheeses made at ambient temperature by Mihretie *et al*. [17]. The rise in moisture accompanying the increase in yield at 450–500 mL/L shows that part of the weight gain is associated with water retention in the curd, in agreement with Mbye *et al*. [15] regarding the higher moisture of cheeses produced by direct acidification.

The large volumes of juice added (150–500 mL/L, equivalent to about 13–33% of the total volume of the mixture) diluted the milk and introduced a substantial acid load. The effect of dilution on the cheese was limited, because most of the water added with the juice separated with the whey during drainingthe moisture of T1–T6 remained almost constant (56.52–56.90%)and because yield was calculated on the weight of milk alone. The acid load, by contrast, was reflected in the higher titratable acidity of the cheese and in the low liking scores for acidity and flavour (Table 4). Both problems could be reduced in future work by using a smaller volume of a more concentrated or acidity-standardised coagulant (for example, concentrated lemon juice or its citric-acid equivalent), by washing the curd to remove excess acid, and by salting the cheese.

Chemical composition

The lemon-juice treatments showed significant changes in chemical composition (Table 3; Figure 3; ANOVA $P < 0.001$ for all four constituents). Protein rose from 8.30% in T1 to 12.84% in T8 and ash decreased from 2.71 to 2.53%, both strongly correlated with dose (r = 0.93 and −0.97; $P < 0.001$). Fat increased from 12.46% in T1 to its highest value (15.79%) in T6 and then declined slightly in T7 and T8 (15.59–15.64%), so that the overall correlation with dose (r = 0.93) conceals a plateau above 400 mL/L. Moisture, by contrast, did not differ significantly among T1–T5 (56.71–56.90%), was slightly lower in T6 (56.52%) and rose significantly only in T7 (57.39%) and T8 (60.31%); consequently its linear correlation with dose was not significant (r = 0.65, P = 0.08). Protein reached a plateau between T5 and T7 (12.14–12.19%; T5 and T7 not significantly different) before the final increase in T8. The increases in moisture and protein are close to those of Mihretie *et al*. [17], who recorded similar values in the highest treatment, and the increase in moisture agrees with Mbye *et al*. [15] regarding the effect of acidification on curd characteristics and water retention.

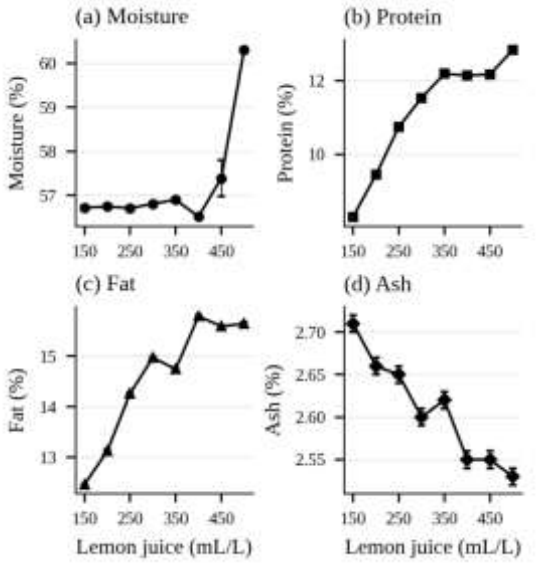


Figure 3. Effect of lemon-juice dose on the (a) moisture, (b) protein, (c) fat and (d) ash

ISSN 2072-3857

contents of camel-milk soft cheese (T1–T8; mean ± SD, n = 3).

The higher moisture at the highest doses is related to the change in the structure of the protein network during rapid acidification at high temperature, while the higher protein reflects greater retention of caseins and heat-denatured whey proteins in the curd. The non-linear change in fat may be related to the whey-separation process and to differences in fat entrapment within the curd, whereas the decrease in ash reflects the passage of minerals and salts into the whey, consistent with the solubilisation of colloidal calcium phosphate and the loss of calcium to the whey as pH falls during acid coagulation [14]. The reference cheeses illustrate the influence of processing conditions: the ginger-extract cheese (C3), coagulated enzymatically at 65 °C, had the lowest moisture (55.14%) and a fat content equal to that of the control (10.51%), whereas the rennet cheese (C2) had intermediate protein (9.15%) and fat (11.42%); these differences arise from coagulant type and processing conditions together and are not attributable to the coagulant alone.

Although the added lemon juice dilutes the milk, the protein and fat contents of the cheese increased with dose. Dilution affects the liquid phase of the mixture, whereas the composition of the curd depends on how completely the caseins, heat-denatured whey proteins and fat are recovered from the milk and on how much serum remains in the curd. At the lower doses (pH 5.30–5.65) coagulation was less complete and part of the protein remained in the whey, whereas at the higher doses the pH approached the isoelectric point of casein (about 4.6) and the proteins aggregated more completely, entrapping more fat [14]; most of the water introduced with the juice was expelled with the whey during draining, as shown by the almost constant moisture of T1–T6 (56.52–56.90%). Because yield increased at the same time, the absolute amount of protein recovered rose far more than its percentage, from about 7.8 g per kg of milk in T1 to about 30.9 g per kg in T8. All compositional values are on a wet basis.

The sum of moisture, protein, fat and ash ranged from 76.97% (C1) to 91.32% (T8), leaving a residual of 8.68–23.03% (Table 3). This fraction consists mainly of carbohydratelactose retained in the serum phase of the curd and, in T1–T8, sugars and citric acid supplied by the lemon juicetogether with other minor constituents not determined individually. The residual decreased steadily as the lemon-juice dose increased (19.81% in T1 to 8.68% in T8), in parallel with the increase in protein and fat, indicating that the more complete protein aggregation at higher doses displaced part of the lactose-containing serum from the curd. The larger residuals of C1–C3 and T1 exceed the carbohydrate content expected from the lactose of camel milk alone, and direct determination of lactose and total solids is recommended in future work to close the mass balance.

The number of significance groups in Table 3 (up to ten letters) results from the very low variability among analytical replicates (SD mostly 0.01–0.05 percentage points), which produced small LSD values (0.02–0.21). Consequently, differences as small as 0.02 percentage points in ash or 0.04 in fat were statistically significant, even though the overall ranges were narrow (ash 2.53–2.83%; fat 10.51–15.79%); for example, C1 and C3 share the letter j for fat because their means are identical (10.51%), whereas all other fat means differ by more than the LSD. These differences are statistically valid under the replicate variance obtained but are of limited practical importance, and the interpretation therefore rests mainly on the dose–response trends (r values) rather than on individual pairwise comparisons.

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Table 4. Sensory evaluation of the lemon-juice cheeses on a nine-point hedonic scale (mean ± SD, n = 40 assessors)

Overall acceptability	Appearance	Flavour	Odour	Colour	Acidity	Softness	Treat.
2.22 ± 0.82 ^{d}	2.20 ± 0.62 ^{c}	2.30 ± 0.98 ^{cd}	2.00 ± 0.85 ^{b}	1.95 ± 0.71 ^{d}	2.54 ± 0.64 ^{cd}	2.32 ± 0.72 ^{d}	T1
2.30 ± 0.71 ^{d}	2.20 ± 0.77 ^{c}	2.52 ± 0.66 ^{bc}	2.13 ± 0.72 ^{b}	2.01 ± 0.61 ^{d}	2.57 ± 1.12 ^{bcd}	2.43 ± 0.80 ^{cd}	T2
2.54 ± 0.71 ^{cd}	2.70 ± 1.21 ^{b}	2.04 ± 0.71 ^{d}	2.11 ± 0.70 ^{b}	2.65 ± 0.94 ^{ab}	2.26 ± 0.85 ^{d}	2.38 ± 0.93 ^{d}	T3
2.41 ± 0.93 ^{cd}	2.32 ± 0.54 ^{c}	2.65 ± 0.60 ^{bc}	2.15 ± 0.76 ^{b}	2.24 ± 0.70 ^{cd}	2.72 ± 0.95 ^{abc}	2.71 ± 0.64 ^{c}	T4
2.74 ± 0.65 ^{bc}	2.31 ± 0.60 ^{c}	2.82 ± 0.76 ^{b}	2.23 ± 0.94 ^{b}	2.36 ± 0.65 ^{bc}	2.78 ± 0.71 ^{abc}	3.25 ± 0.66 ^{b}	T5
2.92 ± 0.73 ^{ab}	2.37 ± 0.55 ^{c}	2.81 ± 1.08 ^{b}	2.26 ± 1.26 ^{b}	2.46 ± 0.49 ^{abc}	2.83 ± 0.95 ^{abc}	3.30 ± 0.71 ^{ab}	T6
3.02 ± 0.72 ^{ab}	3.15 ± 0.73 ^{a}	3.20 ± 0.82 ^{a}	2.74 ± 0.88 ^{a}	2.59 ± 0.83 ^{ab}	2.95 ± 0.97 ^{ab}	3.45 ± 0.52 ^{ab}	T7
3.18 ± 0.74 ^{a}	3.27 ± 0.75 ^{a}	3.36 ± 0.87 ^{a}	2.86 ± 0.97 ^{a}	2.69 ± 0.88 ^{a}	2.98 ± 0.89 ^{a}	3.59 ± 0.61 ^{a}	T8
0.33	0.33	0.36	0.40	0.33	0.39	0.31	LSD
0.97***	0.76*	0.89**	0.89**	0.79*	0.82*	0.96***	r (dose)

Means within a column followed by different superscript letters differ significantly ($P < 0.05$; LSD computed from the pooled within-treatment variance, error df = 312). Scale: 1 = dislike extremely, 5 = neither like nor dislike, 9 = like extremely. r = Pearson correlation between lemon-juice dose and attribute mean across T1–T8 (n = 8); * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$. T1–T8 = 150, 200, 250, 300, 350, 400, 450 and 500 mL lemon juice per litre of camel milk, respectively. C1–C3 (C1 = milk only, no coagulant; C2 = commercial rennet; C3 = crude ginger extract) were not sensory-evaluated.

Sensory evaluation

The sensory attributes differed significantly among the lemon-juice treatments (ANOVA $P < 0.001$ for softness, colour, odour, flavour, appearance and overall acceptability; $P = 0.007$ for acidity), and T8 recorded the highest means for all attributes measured, including overall acceptability (3.18 ± 0.74) (Table 4; Figure 4). Softness and overall acceptability increased most consistently with dose (r = 0.96 and 0.97), and both separated the treatments into a low group (T1–T4) and a high group (T6–T8), with T5 intermediate. Odour, flavour and appearance showed a step change rather than a gradient: T7 and T8 scored significantly higher than T1–T6, which did not differ among themselves for odour and, apart from T3, for appearance. Liking of acidity and colour varied least, with LSD values (0.33–0.39) covering most of the range of means. The general trend agrees with Mihretie *et al*. [17], who noted changes in some sensory attributes with increasing addition of lemon juice.

ISSN 2072-3857

Liking of acidity did not differ significantly among T4–T8 (2.72–2.98), although the dose increased from 300 to 500 mL/L and titratable acidity rose from 0.57 to 0.75%. The hedonic scale measures the degree of liking of an attribute, not the intensity of perceived sourness: all treatments were rated on the "dislike" side for acidity, and liking changed only slightly as acidity increased. In addition, the variation among the untrained assessors was relatively high (SD 0.71–0.97), giving a large LSD (0.39) that masked the small differences between means, and the higher protein content of the high-dose cheeses may have buffered part of the acid and moderated perceived sourness. Measuring sourness intensity with a trained panel or a just-about-right scale would be required to relate perceived acidity directly to lemon-juice dose.

The higher mean relative to the other treatments does not, however, mean that the product achieved high sensory acceptance: the mean overall acceptability of T8 remained below the neutral point of 5 on the nine-point hedonic scale, and the highest attribute mean recorded (softness of T8, 3.59) was likewise on the "dislike" side of the scale. T8 is therefore described as having the highest relative sensory response among the lemon-juice treatments studied, not as being acceptable in absolute terms. The uniformly low scores (2.0–3.6) across all attributes suggest that the strong acidity, the boiling step and the absence of salt or starter culture produced a product unfamiliar to the assessors, and that flavour developmentfor example through salting, mild ripening or the addition of herbsshould be addressed before consumer trials; the low acceptability of plain camel-milk cheeses and the need for flavour improvement have been noted previously [4,16]. Consequently, the manufacture of camel-milk cheese by this method in its current form cannot be recommended for commercial production or direct consumer use: the results support lemon juice as a technically effective coagulant in terms of yield and composition, but the product requires sensory improvement before any practical recommendation can be made.

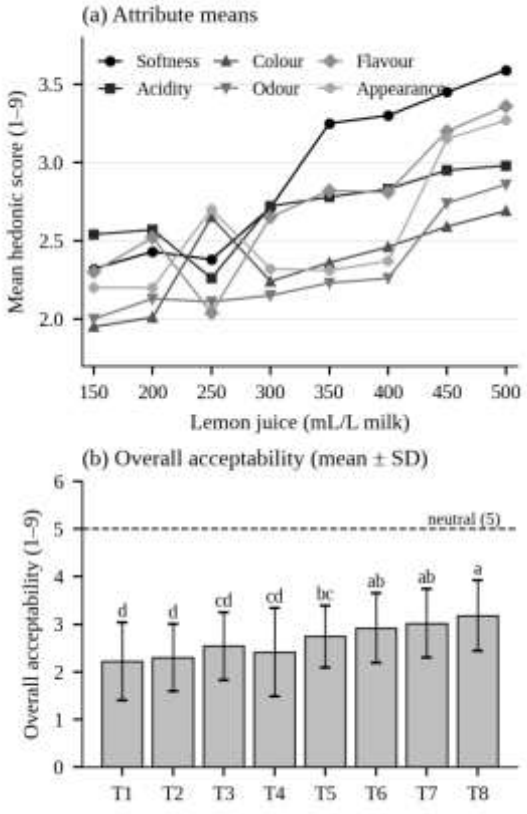


Figure 4. Sensory scores of the lemon-juice cheeses: (a) mean scores of six attributes versus lemon-juice dose; (b) overall acceptability (mean ± SD, n = 40) of T1–T8, with LSD letters. The dashed line marks the neutral point (5) of the nine-point hedonic scale.

Performance of the reference treatments (rennet and ginger extract)

The ginger-extract treatment (C3) recorded a yield of 11.51%, a titratable acidity of 0.38% and a pH of 5.80, and the rennet treatment (C2) a yield of 10.63%, an acidity of 0.35% and a pH of 6.32 (Table 2). These values are not directly comparable with those of the lemon-juice cheeses, because each coagulant was applied under the temperature, pH and time it requires (Table 1): the ginger

cheese was coagulated enzymatically at pH 5.0 and 65 °C for 30 min, the rennet cheese at near-neutral pH and mild temperature, and the lemon-juice cheeses by acidification at boiling temperature for 10 min. The differences observed therefore reflect coagulant type and processing conditions together. Hailu *et al*. [8] demonstrated clotting activity of ginger extract in camel milk at pH 5.0, 65 °C and 10% concentration, conditions close to those used for C3 in the present study, and Fguiri *et al*. [6] showed that the efficiency of plant coagulant extracts is affected by the extraction method and coagulation conditions. The findings of Huang *et al*. [9] support the enzymatic interpretation, since ginger proteases possess milk-clotting activity with selective hydrolysis of κ-casein. Enzymatic coagulation at pH 5.0–6.3 yielded curds of lower moisture (55.14% for C3) and lower fat retention (10.51–11.42%) than the acid–heat curds, while the yields of C2 and C3 (10.63 and 11.51%) were comparable to those of the lowest lemon-juice doses (T1–T4: 9.36–11.14%) but far below those of T7 and T8. In addition, extraction of the ginger proteases at room temperature for one hour may have reduced their activity through autolysis, which could have contributed to the modest yield of C3. The reference treatments thus serve to illustrate the different behaviour of enzymatic and acid–heat coagulation in the manufacture of soft cheese from camel milk, and a formal comparison of coagulant types would require a design in which temperature, pH and holding time are equalised or systematically varied.

Conclusions

1. Cheese yield, titratable acidity and the extent of pH fall increased with increasing lemon-juice dose within the range 150–500 mL/L, with yield rising steeply above 300 mL/L; the trend is consistent with Mihretie *et al*. [17].

2. Treatment T8 (500 mL lemon juice/L milk) recorded the highest yield (24.06%), moisture (60.31%) and protein (12.84%) among the lemon-juice treatments, demonstrating its efficiency in achieving the highest yield within the concentrations studied.

3. The chemical composition of the cheese changed with increasing lemon-juice dose: protein rose and ash decreased continuously, fat reached its maximum in T6 (400 mL/L) and then plateaued, and moisture rose significantly only at 450–500 mL/L.

4. T8 recorded the highest sensory scores among the lemon-juice treatments, with a mean overall acceptability of 3.18 ± 0.74 out of 9, which is relatively the highest among the treatments but below the neutral point and therefore does not represent high sensory acceptance. The process in its current form cannot therefore be recommended for commercial production until the sensory quality of the cheese is improved.

5. The rennet (C2) and ginger-extract (C3) reference treatments differed from the lemon-juice cheeses in yield, acidity, pH and composition; because each coagulant was applied under its own temperature, pH and time, these differences reflect coagulant type and processing conditions together and do not constitute a like-for-like comparison of coagulants.

Recommendations

1. Evaluating the performance of lemon juice at the concentrations studied in different batches of camel milk and under different seasons and processing conditions, to support the consistency of the results and widen their applicability.

2. Studying the effects of pH, temperature and coagulation time systematically in a factorial design that applies the same conditions to all coagulants, to determine the most suitable processing conditions for

ISSN 2072-3857

lemon juice as a natural acid coagulant and to allow a valid comparison with rennet and plant coagulants, including reducing the volume of juice added by using concentrated or acidity-standardised lemon juice to limit dilution of the milk and excessive acidity of the cheese, and preparing the ginger extract at 4 °C to preserve its protease activity.

3. Completing the evaluation of cheese safety and quality by carrying out appropriate microbiological tests and studying storage stability under refrigeration, with monitoring of pH, water activity and texture during storage, and examining the effect of a longer holding period (e.g. 24 h) before analysis.

4. Developing the sensory evaluation with a trained panel and a larger, more diverse group of consumers, including the reference cheeses in the same session, and investigating salting, flavouring or mild ripening to improve acceptability.

5. Conducting an economic analysis of the process to determine the cost of using lemon juice, the return per unit of milk and the practical feasibility.

Acknowledgment: The authors thank the staff of Al-Ameen Laboratory, Najaf, for providing the laboratory facilities and technical assistance, and the teaching staff and students of the Department of Food Sciences who kindly participated in the sensory evaluation.

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ISSN 2072-3857