Applied Food Research 4 (2024) 100469

Contents lists available at ScienceDirect

Applied Food Research

journal homepage: www.elsevier.com/locate/afres

Effects of optimizing fermentation time and stabilizers using response surface methodology on physicochemical properties of camel milk yoghurt

Philip K. Marete [a], Alfred M. Mariga [a], Guyo Huka [b], Levi Musalia [c], Eunice Marete [d], Julius M. Mathara [e], Joshua M. Arimi [a,*]

[a] Department of Food Science, Meru University of Science and Technology, Meru, Kenya
[b] Department of Business Management, Meru University of Science and Technology, Meru, Kenya
[c] Department of Dry Land Agriculture and Natural Resources, Tharaka University College, Tharaka-Nithi, Kenya
[d] Department of Physical Sciences, Meru University of Science and Technology, Meru, Kenya
[e] Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology, Juja, Kenya

ARTICLE INFO

Keywords:
Optimization
Viscosity
Fermentation time
Camel milk
Yoghurt

ABSTRACT

The objective of this study was to produce camel milk yoghurt with desired qualities using optimized processing conditions (fermentation time) and ingredients (stabilizer and calcium chloride). The conditions were obtained through Response Surface Methodology (RSM) by lactic acid fermentation by inoculating the milk with *Lactobacillus delbrueckii* subsp. *Bulgaricus* (YF-L903, CHR Hansen, Denmark. The study also determined the effects of fermentation time and ingredients on the quality of yoghurt. Fermentation time ranged from 2 to 22 h while stabilizer (corn starch) and calcium chloride (salt) ranges were 1.65–3.34 and 0.061–1.23 % respectively. The quality was monitored hourly for a fermentation period of 2–22 h by determining pH, total titritable acidity (TTA) and viscosity. Results indicated that viscosity was influenced by fermentation time, stabilizer and calcium chloride. The viscosity was increased from 0.01 to 0.4 and 0.01 to 0.3 by fermentation time, 0.01 to 0.2 and 0.01 to 0.3 by stabilizer and 0.01 to 0.5 and 0.01 to 0.6 Pa s by calcium chloride. Whereas the combined effects of calcium chloride and stabilizer increased the viscosity of yoghurt to 0.94 Pa s. Prolonged fermentation time, led to an increase in TTA and a decrease in pH. The finding from this study indicated that the optimal conditions required to produce camel milk yoghurt with desired qualities are a fermentation time of 10 h using 2.33 and 0.60 % corn starch and calcium chloride respectively. Under these conditions the produced camel milk yoghurt quality properties were a pH of 4.07, 0.32 % TTA and a viscosity of 0.35 Pa s.

1. Introduction

Camels are mostly domesticated in arid and semi-arid regions since they are well adapted to endure the harsh climatic conditions. According to Steve Machan et al. (2022) Isiolo (ASAL), a County in Kenya, produced 1,718,374 liters of camel milk in 2019. According to a study by Karaman et al. (2021) raw camel milk has a pH of 6.22, while the percentages of TTA, fat, protein and ash are 0.13, 2.30, 2.70 and 0.72 respectively. One of the most well-known fermented camel milk products is yoghurt which provides additional nutritional benefits over milk. Yoghurt comes from the Turkish word ``jugurt,'' which means dense or thick (Moss & Adams, 2008). Milk sugar (lactose) is fermented by bacteria into lactic acid to create yoghurt, giving yoghurt its gel-like texture and the characteristic taste. Two bacteria, *Lactobacillus bulgaricus* and *Streptococcus thermophilus*, are added to whole or skim milk to make yoghurt (Obi et al., 2018). Persons who experience lactose intolerance can enjoy yoghurt with no side effects since the lactose in the milk is converted to lactic acid by the bacterial culture (Savaiano, 2014). There are different forms of yoghurt including; drinkable low fat or fat free, fruity or cereal flavored (Kolapo, 2007). Additionally yoghurt can be classified according to physical nature of yoghurt which can be solid, semi-solid or fluid, while other forms include dried, frozen, natural/ non flavored and herbal yoghurt (Weerathilake et al., 2014).

Manufacturing yoghurt from camel milk with similar viscosity and sensorial properties to bovine milk yoghurt is reported to be challenging (Berhe et al., 2018). The problem with camel milk yoghurt is the thin consistency of the product (Berhe et al., 2018). Yoghurt texture is a very important parameter that affects the appearance, mouth feel, and

* Corresponding author.
E-mail address: jarimi@must.ac.ke (J.M. Arimi).

https://doi.org/10.1016/j.afres.2024.100469
Received 11 April 2024; Received in revised form 27 July 2024; Accepted 7 August 2024
Available online 14 August 2024

overall acceptability. Camel milk has been reported not to be easily fermentable (Berhe et al., 2018). According to Farrah and Ruegg (1991), the difficulties of processing camel's milk may be caused by the small size and varied size distribution of the micellar structures of caseins and the globular structures of lipids (Farah & Rüegg, 1991).

Nevertheless, there are reports that indicate the possibility of yoghurt production from camel milk (Eissa et al., 2011). Hashim et al. (2009) have reported that the firmness of camel milk yoghurt could be improved by adding gelatin, alginate, and calcium. Additionally, Ibrahim and Khalifa (2015a) suggested that the use of exopolysaccharide producing starter cultures could improve the texture of camel milk yoghurt. Moreover, a study comparing the effects of different stabilizing agents (corn starch, modified starch and calcium chloride) on camel milk yoghurt thickness, reported that corn starch produced yoghurt recorded the highest viscosity Oselu et al. (2022).

It is hypothesized that optimizing processing conditions and quantities of ingredients in camel milk yoghurt processing can be carried out to obtain a product with acceptable qualities. A study to optimize processing conditions for camel milk yoghurt production was carried out using linear programming with the goal of yielding a high-quality stirred yoghurt product by Habte and Emire (2016). Viscosity (rheological improvement), syneresis, and maximum fat level of the yoghurt were used as response variables, whereas, total solid level of milk, fat content, and level of pectin were used as process parameters. The study concluded that good quality stirred yoghurt (viscosity of 0.306 Pa s) could be manufactured using 12.16 % total solid content, 0.9 % fat level of camel milk and a ratio of 0.0015 % of commercial stabilizer (pectin).

Camel milk yoghurt has also been produced by mixing camel milk with milk from other animal species with the aim of improving viscosity. In a study by El-gammal et al. (2007), buffalo milk and sodium alginate were used in making camel milk yoghurt and the chemical, physicochemical, microbiological and sensory evaluations analysis carried out during a storage period of up to15 days. When buffalo's milk was mixed with camel milk, diacetyl and acetyl methyl carbinol levels rose during the first ten days of storage, then fell over the subsequent five days. The inclusion of sodium alginate increased the yoghurt's body and texture, resulting in an unusual jelly-like consistency (El-gammal et al., 2007).

In another study three treatments were evaluated using camel milk and cow milk: A (75 % camel milk + 25 % cow milk), B (50 % camel milk + 50 % cow milk), and C (25 % camel milk + 75 % cow milk) Mustafa et al. (2015). The study reported that yoghurt prepared from pure cow milk recorded the highest viscosity and cow milk blended with camel milk yielded the greatest texture results compared to using camel milk alone. The study concluded that camel milk yoghurt has lower physiochemical and sensory quality than cow milk. In addition the study showed that combining high percentages of cow milk (75 %) with camel milk (25 %) improved physiochemical properties (protein, fat, lactose, pH) and sensory evaluation (flavor, overall acceptability) of camel's milk yoghurt.

Due to the existing difficulties in processing camel milk yoghurt using the same technology as bovine milk, this study was carried out with the aim of optimizing conditions and ingredients to process camel milk yoghurt. The response surface methodology (RSM) using the central composite design (CCD) was applied to optimize the conditions; fermentation time (6 to 18 h) and ingredients i.e. stabilizer (2 to 3 %) and calcium chloride (0.3 to 1 %) were used. The quality of the product was determined by analyzing the physicochemical properties during fermentation (pH, titratable acidity and viscosity).

2. Materials and methods

2.1. Sample collection and preliminary analysis

Camel milk was obtained from camel farmers affiliated to Anolei women Co-operative society in Isiolo town, Isiolo County, Kenya. The milk was delivered to Meru University of Science and Technology (MUST), Meru, Kenya, Food Science laboratories and stored at 4 °C for processing and subsequent analysis.

2.2. Experimental design

A response surface method (RSM) experiment was designed using design expert version 13 software (Stat-Ease company, Minneapolis, Minnesota, USA) to determine the independent variables and their corresponding levels (Table 1) as well as optimize the fermentation time, percentage of calcium chloride and stabilizer to be used to make yoghurt. A total of 20 experiments were designed (Table 2). Response variables included pH, Titratable acidity (TTA) and viscosity. For each response variable, analysis of variance (ANOVA) was conducted to determine significant differences among the treatments. If the response showed significant differences, data were analyzed using multiple regression procedures to estimate the linear, quadratic and interactive effects of fermentation time, salt and stabilizer.

2.3. Yoghurt preparation

Water used to sterilize the equipment used in yoghurt preparation was heated to 95 °C by testing using a thermometer (Model:SR-6, manufacturer, city, country). Then 3 liters of milk sample were weighed and used to prepare yoghurt. The milk was initially heated in a water bath to 40 °C, then sugar (6 %) and calcium chloride and thickener were added according to the proportions in the experiment research design. The milk was subsequently pasteurized at 85 °C and the temperature maintained for 30 min in a controlled water bath to disperse hydrocolloids in milk. The milk was eventually cooled to 40 °C, transferred into a 5-liter capacity cheese vat (FT20-MK11, Armfield, UK), inoculated using commercial yoghurt culture (*Lactobacillus delbrueckii* subsp. *Bulgaricus*) (YF-L903, CHR Hansen, Denmark) and the fermentation carried out at 42 ± 1 °C according to the corresponding periods on the experiment research design.

2.4. Determination of the physicochemical properties of yoghurt

Samples were collected using sterilized equipment and analyzed for pH, viscosity and total titratable acidity (TTA) according to the designed experiments (Table 1).

2.5. Determination of pH

The pH of yoghurt was measured according to method described by Galeboe et al. (2018) using electronic pH meter (Universal motion, model H1-1131B, Mumbai, India).

2.6. Determination of total titratable acidity (TTA)

The TTA of yoghurt was analysed using a method described by Zainoldin and Hj Baba (2009) and the formula below was used to calculate the content of titratable acids (lactic acid percentage equivalent)

$$\text{Lactic acid } (\%) = \frac{10 \times 0.1 \times \text{V NaOH} \times 0.009}{\text{ml of sample used}} \times 100$$

where: 10 is the dilution factor, V NaOH the Volume of NaOH used to neutralize the lactic acid and 0.1 the Normality of NaOH.

Table 1
Independent variables and their corresponding levels for camel milk yoghurt optimization.

		−α	−1	0	+1	+α
Fermentation time (h)	X_1	2	6	6	18	22
Stabiliser (%)	X_2	1.65	2	2.5	3	3.34
Calcium chloride (%)	X_3	0.061	0.3	0.6	1	1.23

Table 2
The variations of time, calcium chloride and corn starch used in response surface method (RSM).

Run	Time	Ingredients		Output		
Run	Fermentation time (h)	Stabilizer (%)	Salt (%)	Viscosity (Pa s)	TTA (%)	pH
1	12	2.5	0.65	0.12	0.78	3.98
2	12	2.5	0.65	0.56	0.24	3.90
3	12	1.65	0.65	0.34	0.51	3.94
4	18	2	0.3	0.21	0.54	3.79
5	12	2.5	0.65	0.16	0.19	3.97
6	18	3	0.3	0.18	0.89	3.80
7	2	2.5	0.65	0.04	0.07	5.13
8	6	2	0.3	0.06	0.15	4.51
9	18	2	1	0.94	0.84	4.03
10	12	2.5	0.65	0.90	0.32	4.00
11	22	2.5	0.65	0.96	0.85	3.97
12	18	3	1	0.755	0.89	3.91
13	6	3	1	0.69	0.14	4.25
14	12	2.5	0.65	0.09	0.67	4.01
15	12	3.34	0.65	0.98	0.23	3.98
16	12	2.5	1.24	0.46	0.25	4.00
17	6	2	1	0.713	0.14	4.33
18	12	2.5	0.06	0.06	0.19	3.95
19	12	2.5	0.65	0.18	0.31	4.02
20	6	3	0.3	0.37	0.13	4.45

2.7. Apparent viscosity measurements

Apparent viscosity was determined by the use of a concentric cylinder rheometer (Rheolab QC-Anton Paar, Austria) with slight modification of the method described by Renan et al. (2009). The bob was allowed to rotate in 10 ml yoghurt sample for 2 min. Apparent viscosity was automatically computed using the software, RheoPlus/32, Anton Paar, Austria with readings being taken after 12 s (10th point) of the shear stress- shear rate (64/s) spectrum display on the digital output of the rheometer. The readings were expressed in Pa s

The use of Response Surface Methodology in an experimental design allows researchers to optimize parameters in product development. In this study RSM was used to optimize fermentation time, stabilizer and calcium chloride used in camel milk yoghurt production. Table 3 shows the conditions, ingredients and parameters optimized during camel milk yoghurt processing. In the optimization step, fermentation time was minimized. The objective was to minimize the incubation time of yoghurt especially during commercial processing. The amount of stabilizer was maximized because from the results it increased the viscosity of yoghurt. The importance of stabilizer was however allocated 3 instead of the maximum value of 4 because of the economic implications in using higher amount of stabilizer during commercial processing. The quantity of calcium chloride was minimized because it could impart negatively on the organoleptic characteristics of the yoghurt. However, the importance was allocated 3 because it was shown to increase the viscosity of yoghurt. The importance of the viscosity of yoghurt was allocated the highest value, 4 and at the same time maximized because the main problem associated with camel milk yoghurt when processed using the same technique as bovine milk is the poor viscosity. Hence, by improving the viscosity, camel milk yoghurt possessing the desired qualities can be produced.

Table 3
Conditions set for optimization of camel milk yoghurt.

Constraints				
Name	Goal	Lower limit	Upper limit	Importance
A:Fermentation	minimize	2	22	3
B:Stabilizer	maximize	1.65	3.34	3
C:Calcium chloride	minimize	0.06	1.23	3
Viscosity	maximize	0.03	0.98	4
TTA	none	0.07	0.89	3
pH	none	3.79	5.13	3

3. Results and discussion

3.1. Effects of fermentation time, calcium chloride (salt) and corn starch (stabilizer) on pH of yoghurt

According to modeling results, the combined effects of calcium chloride and stabilizer decreased yoghurt pH from 4.1 to 3.8 (Fig. 1a). From the study an increase in fermentation time from 2 to 22 h led to a decrease in the pH of yoghurt from 4.7 to 3.7 in the combined effect of concentration of calcium chloride and fermentation time (Fig. 1b). Furthermore, increasing the concentration of calcium chloride from 0.06 to 1.23 % reduced the pH from 4.7 to 4.6 (Fig. 1b). The combined effect of increasing the fermentation time and concentration of stabilizer reduced the pH of yoghurt to 3.6 (Fig. 1c). Additionally, an increase in fermentation time from 2 to 22 h reduced the pH from 5.2 to 3.6 in the combined effect of concentration of stabilizer and fermentation time (Fig. 1c). Thus, fermentation time decreased the pH of yoghurt. The reason for the decreasing pH of yoghurt could be as a result of the action of acid-producing microorganisms due to their increased and sustained metabolic activity (Gassem & Abu-Tarboush, 2000), this resulted in progressive production of lactic acid with consequent depression of pH. Similar observations on the effects of calcium chloride on pH were reported by Szajnar et al. (2016). In a study to evaluate the effects of fortifying yoghurt with various calcium compounds, they reported that a dose of 50 mM of calcium chloride reduced the pH from 6.6 to 5.8. Similarly, a decrease in the pH of yoghurt resulting from addition of calcium chloride was reported by Ramasubramanian et al. (2008). Additionally, the study indicated that addition of calcium chloride increased the calcium ions concentration in yoghurt which subsequently led to an increase in hydrogen ions concentration which decreased the pH. Studies have shown that different stabilizers have different effects on pH of yoghurt due to different buffering capabilities as well as the concentration of the stabilizers. Stabilizers like corn starch, gelatin and carboxymethyl cellulose (CMC) have been shown to decrease the pH of yoghurt as fermentation time increased in a study by Alakali et al. (2008).The study also showed that the pH of yoghurt during fermentation generally decreased with an increase in concentration of the stabilizers. The decrease in pH as the concentration of stabilizer was increased, may be attributed to the fermentation of the stabilizer by the lactic acid bacteria and the acidity effect of the added stabilizers (Ibrahim & Khalifa, 2015).

3.2. Effects of fermentation time, calcium chloride (salt) and corn starch (stabilizer) on tta of yoghurt

Modeling results indicated that increasing calcium chloride concentration from 0.06 to 1.23 % slightly increased the titratable acidity of yoghurt from 0.23 to 0.50 % (Fig. 2a). Increasing the concentration of stabilizer from 1.65 to 3.34 % also increased the acidity of yoghurt from 0.31 to 0.39 % (Fig. 2a). The combined effects of increasing the concentration of calcium chloride and stabilizer increased the total acidity of yoghurt to 0.43 % (Fig. 2a). Yoghurt acidity rose from 0.01 to 0.83 % as fermentation time increased from 2 to 22 h (Fig. 2b). Notably, the acidity was also increased by the combined effects of fermentation time and calcium chloride concentration to 0.83 % (Fig. 2b). The combined effect of increasing the fermentation time and concentration of stabilizer contributed to an increment of acidity to 0.86 % (Fig. 2c). Increasing fermentation time increased TTA of yoghurt. The results were in agreement with those reported by Oselu et al. (2022) who noted with longer fermentation times (0–6 h), the TTA of camel milk yoghurt increased. Similarly (Ibrahem & El Zubeir, 2016) observed a sharp increase in lactic acid content up to third hour when fermenting camel milk yoghurt for six hours. Fermentation time had an effect on TTA concentration as results indicated progressive production of lactic acid

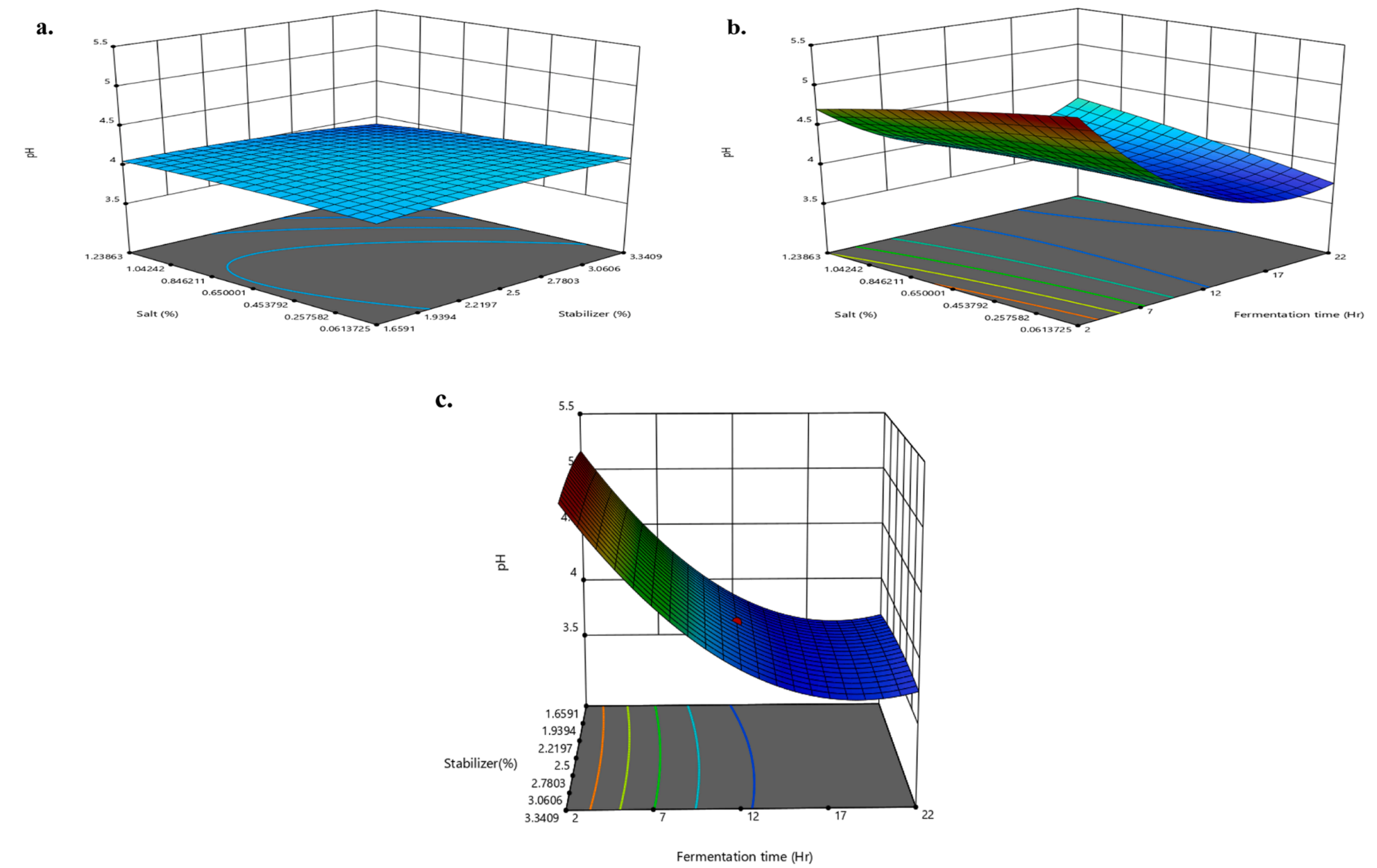

Fig. 1. The effect of calcium chloride (salt) concentration (0.06–1.23 %) and stabilizer concentration (1.65–3.34 %) (1a), fermentation time (2–22 h) and calcium chloride concentration (0.06–1.23 %) (1b) and fermentation time (2–22 h) and stabilizer concentration (1.65–3.34 %) (1c) on pH of camel milk yoghurt.

during fermentation period. Studies have shown that calcium chloride used in production of camel milk yoghurt affects its TTA. Studies have also demonstrated that $CaCl_2$ addition reinforces the gel strength of camel milk yoghurt (Hashim et al., 2009). In a study to evaluate the effect of adding calcium compounds to various types of yoghurts, Szajnar et al. (2016) reported that the acidity similar to the sample with no calcium compound, was found only in yoghurt with calcium chloride compared with other calcium compounds. Results from this study agreed with those previously reported by Szajnar et al. (2016) in a study which indicated that calcium chloride had no noticeable effect on TTA after 4 h fermentation time. The combined effects of increasing calcium chloride and fermentation time increased the TTA. Similar finding were observed by Oselu et al. (2022) who reported that the TTA of camel milk yoghurt containing calcium chloride increased with fermentation time from 0 to 6 h from 0.18 to 0.78 %. A study by Eze et al. (2021) reported different stabilizers have different effects on TTA. The study showed gum Arabica increased the TTA of yoghurt more compared to corn starch. The rate at which stabilizers affect production of lactic acid in milk could be attributed to the ability of the stabilizer to form highly viscous systems as shown by Alakali et al. (2008) explaining the difference in effect of different stabilizers on TTA. Evaluating the impact of adding three combinations of stabilizers i.e. combination of gelatin, mono and diglyceride of fatty acids, combination of guar gum, sodium CMC and mono and diglyceride of fatty acids, and the third combination of modified starch and mono and diglyceride of fatty acids to camel milk yoghurt (Ibrahim & Khalifa, 2015b) noted a rise in TTA of camel milk yoghurt compared to yoghurt with no stabilizers. In a study to determine the effects of stabilizers on short-set yoghurt, Eze et al. (2021) recommended the use of corn starch and gum Arabica compared over carboxyl methylcellulose (CMC). This is because they have low viscosity and allowed greater freedom of mobility of reactants, which enables reacting species to come together for fermentation to take place. Similar results were noted in studies carried out by Alakali et al. (2008) that indicated corn starch was found to have less inhibitory effect on the measured titratable acidity compared to gelatin and CMC at similar levels or concentrations.

3.3. Effects of fermentation time, calcium chloride (salt) and corn starch (stabilizer) on viscosity of yoghurt

Results obtained after modeling indicated that as concentration of calcium chloride increased from 0.06 to 1.23 %, the viscosity of yoghurt increased from 0.01 to 0.63 Pa s. (Fig. 3a). The same effect was observed for corn starch on viscosity, as the concentration of corn starch increased from 1.65 to 3.34 % the viscosity increased from 0.01 to 0.63 Pa s (Fig. 3a). The viscosity exhibited a further increase to 1.04 Pa s from the combined effect of increasing the concentration of calcium chloride and stabilizer (Fig. 3a). Prolonging the fermentation time from 2 to 22 h led to an increase in the viscosity of yoghurt from 0.01 to 0.32 Pa s (Fig. 3b). In addition, the viscosity of yoghurt was observed to increase from 0.01 to 0.49 Pa s (Fig. 3b) as the concentration of calcium chloride increased from 0.06 to 3.34 % (Fig. 3b). The combined effects of increasing concentration of calcium chloride and the fermentation time resulted in the increase of the viscosity to 0.90 Pa s (Fig. 3b). Similar trend was observed for the combined effects of increasing the concentration of stabilizer and the fermentation time that increased the viscosity of yoghurt from 0.02 to 0.70 Pa s (Fig. 3c).

The results on the effects of fermentation time on yoghurt viscosity are in agreement with those obtained by Krisnaningsih et al. (2019) who recorded the viscosity of yoghurt to be 0.25 and 0.27 Pa s for yoghurt incubated for 18 and 42 h respectively. Similarly in a study by Bulca et al. (2019) comparing yoghurts processed using camel milk mixed with

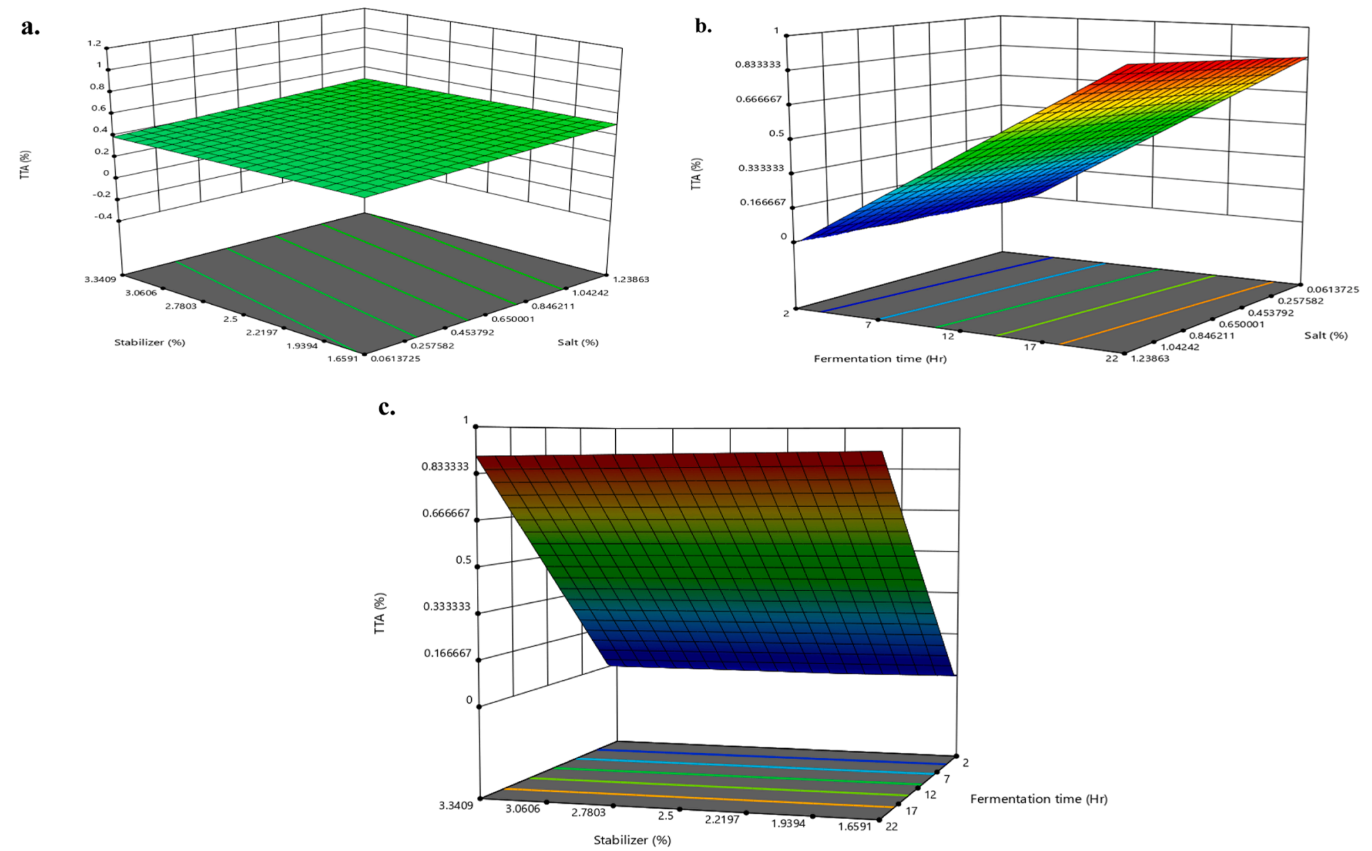

Fig. 2. The effect of calcium chloride (salt) concentration (0.06–1.23 %) and stabilizer concentration (1.65–3.34 %) (2a), fermentation time (2–22 h) and calcium chloride concentration (0.06–1.23 %) (2b) and fermentation time (2–22 h) and stabilizer concentration (1.65–3.34 %) (2c) on TTA of camel milk yoghurt.

sheep and goat milk, observation was made indicating the viscosity of yoghurt increased with increase in fermentation period.

Calcium chloride and stabilizers have been used to enhance the texture of camel milk yoghurt to obtain the desired viscosity. A study by Hashim et al. (2009) reported that addition of 0.75 % sodium alginate plus 0.075 % calcium chloride produced acceptable camel milk yogurt similar to cow's milk yoghurt. Camel milk yoghurt with improved viscosity has been produced by addition of 1.5 ml/L of food-grade calcium chloride (Galeboe et al., 2018). According to Ramasubramanian et al. (2008) calcium ion combined with low pH contribute to a firmer gel by decreasing the steric repulsion between the casein micelles building intense cross-linking between the micelles. Similarly various stabilizers have been used to improve viscosity of camel milk yoghurt. In a study by Ibrahim and Khalifa (2015b) using gelatin E441, mono & diglyceride of fatty acids E471, guar gum E412, sodium carboxymethyl cellulose E466 and mono & diglyceride of fatty acids E471 and modified starch E1422 and mono and diglyceride of fatty acids E471 concluded that to prevent serum separation, stabilizers can be used in camel milk yoghurt to adjust the viscosity. The viscosity of camel milk yoghurt is improved by addition of starch which forms a gel after heating. During heating the starch absorbs water, gelatinizes and swells thereby increasing the solution viscosity (Mishra & Rai, 2006). Studying the effects of corn starch on camel milk yoghurt (Muliro et al., 2013) reported that corn starch serves well as a thickener but it requires combining with a gelling agent like gelatin to reduce syneresis. Additionally high levels of fat may also contribute to yoghurts having a higher viscosity when homogenized milk is used in the manufacturing process. Homogenization promotes casein and fat globules to form a copolymer, strengthening the gel network (Isanga & Zhang, 2009).

Optimization results indicated that the highest value of viscosity (0.34 Pa s) would be obtained when camel milk is fermented for 10 h by using a concentration of 2.33 and 0.60 % of stabilizer and calcium chloride respectively (Table 4).

For validation purposes camel milk yoghurt was processed using the above optimized conditions. The results for viscosity, TTA and pH were found to be 0.370 ± 0.04 Pa s, 0.30 ± 0.07 % and 4.05 ± 0.03 respectively.

3.4. The model equations for pH, TTA and viscosity

First order/linear Equations

$$\mathrm{Model}_{\mathrm{viscosity}} = -0.647360 + 0.021992X_{\mathrm{Fermentationtime}} + 0.168826X_{\mathrm{Stabilizer}} + 0.615334X_{\mathrm{Salt}}$$

$$\mathrm{Model}_{\mathrm{TTA}} = -0.180517 + 0.047869X_{\mathrm{Fermentationtime}} - 0.011926X_{\mathrm{Stabilizer}} + 0.082035X_{\mathrm{Salt}}$$

$$\mathrm{Model}_{\mathrm{pH}} = 4.73660 - 0.048111X_{\mathrm{Fermentationtime}} - 0.027403X_{\mathrm{Stabilizer}} + 0.008878X_{\mathrm{Salt}}$$

Second order/quadratic Equations

$$\mathrm{Model}_{\mathrm{Viscosity}} = 1.281148 + 0.021722X_{\mathrm{Fermentationtime}} - 1.690642X_{\mathrm{Stabilizer}} + 1.515874X_{\mathrm{Salt}} - 0.021417X_{\mathrm{Fermentationtime}}x_{\mathrm{Stabilizer}} + 0.019762X_{\mathrm{Fermentationtime}}x_{\mathrm{Salt}} - 0.350001X_{\mathrm{Stabilizer}}x_{\mathrm{Salt}} + 0.001707X^2_{\mathrm{Fermentationtime}} + 0.468794X^2_{\mathrm{Stabilizer}} - 0.202063X^2_{\mathrm{Salt}}$$

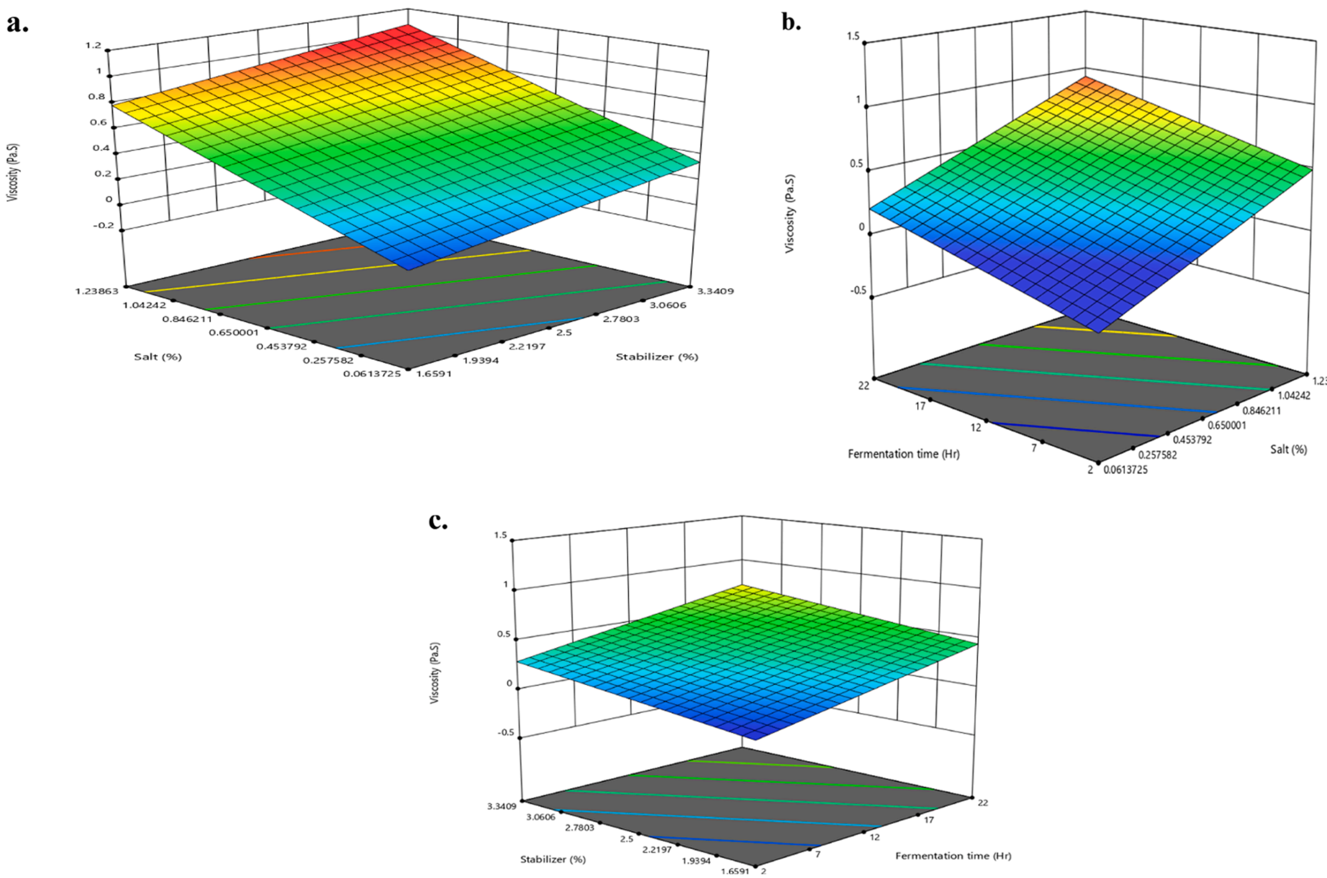

Fig. 3. The effect of calcium chloride (salt) concentration (0.06–1.23 %) and stabilizer concentration (1.65–3.34 %) (3a), fermentation time (2–22 h) and calcium chloride concentration (0.06–1.23 %) (3b) and fermentation time (2–22 h) and stabilizer concentration (1.65–3.34 %) (3c) on viscosity of camel milk yoghurt.

Table 4
The output of the optimized ingredients on the viscosity, TTA, pH and desirability.

Stabilizer (%)	Calcium chloride (%)	Fermentation time (h)	Viscosity (Pa s)	TTA	pH	Desirability
2.33	0.60	10	0.35	0.34	4.07	0.51

$$\mathrm{Model}_{TTA} = 0.389785 - 0.034888X_{Fermentationtime} - 0.271828X_{Stabilizer} + 0.844468X_{Salt} + 0.017500X_{Fermentationtime}x_{Stabilizer} + 0.017857X_{Fermentationtime}x_{Salt} - 0.200001X_{Stabilizer}x_{Salt} + 0.001142X^2_{Fermentationtime} + 0.035981X^2_{Stabilizer} - 0.366706X^2\mathrm{Salt}$$

$$\mathrm{Model}_{pH} = 5.187152 - 0.211386X_{Fermentationtime} + 0.343522X_{Stabilizer} - 0.147183X_{Salt} + 0.001396X_{Fermentationtime}x_{Stabilizer} + 0.043383X_{fermentationtime}x_{Salt} - 0.104166X_{Stabilizer}x_{Salt} + 0.005483X^2_{Fermentationtime} - 0.063994X^2_{Stabilizer} - 0.080092X^2_{Salt}$$

4. Conclusion

The results showed that by optimizing fermentation time, stabilizer (corn starch) and calcium chloride (salt) it was possible to process camel milk yoghurt with desirable characteristics. The highest increment in viscosity of yoghurt was observed in the combined effects of calcium chloride and stabilizer concentration which was 1.04 Pa s, while the highest increase in TTA was observed in the combined effects of stabilizer and fermentation time which was 0.86 %. The lowest pH level was noted to be 3.541 in the combined effects of fermentation time and stabilizer. From this study, it can be concluded that, in order to process camel milk yoghurt of desirable viscosity, the fermentation time as well as the percentage of corn starch and calcium chloride should be maintained at: 10 h, 2.33 % and 0.60 % respectively.

Ethical statement - studies in humans and animals

As the authors of the submitted paper, we wish to declare that the study carried out didn't involve human or animal studies.

CRediT authorship contribution statement

Philip K. Marete: Writing – review & editing, Writing – original draft, Validation, Software, Methodology, Formal analysis, Data curation. **Alfred M. Mariga:** Writing – review & editing, Validation, Supervision, Investigation. **Guyo Huka:** Validation, Project administration, Investigation, Funding acquisition, Conceptualization. **Levi Musalia:** Validation, Resources, Project administration, Investigation, Funding acquisition, Conceptualization. **Eunice Marete:** Visualization, Resources, Project administration, Investigation, Funding acquisition, Conceptualization. **Julius M. Mathara:** Visualization, Validation, Resources, Project administration, Investigation, Funding acquisition, Conceptualization. **Joshua M. Arimi:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

Acknowledgments

The authors wish to acknowledge funding from Kenya's National Research Fund (NRF) as part of the 2nd multi-institutional, multidisciplinary research grant. We also appreciate the camel milk provided by the Anolei Women Group Isiolo.

Appendix A. ANOVA for Quadratic model for pH

Source	Sum of squares	df	Mean square	*F*-value	*p*-value	
Model	1.77	9	0.1971	35.10	<0.0001	significant
A-A	0.0026	1	0.0026	0.4565	0.5146	
B-B	0.0001	1	0.0001	0.0235	0.8813	
C-C	1.13	1	1.13	201.13	<0.0001	
AB	0.0027	1	0.0027	0.4734	0.5071	
AC	0.0001	1	0.0001	0.0250	0.8776	
BC	0.0664	1	0.0664	11.82	0.0063	
A^2	0.0037	1	0.0037	0.6573	0.4364	
B^2	0.0014	1	0.0014	0.2472	0.6298	
C^2	0.5457	1	0.5457	97.17	<0.0001	
Residual	0.0562	10	0.0056			
Lack of Fit	0.0464	5	0.0093	4.75	0.0561	not significant
Pure Error	0.0098	5	0.0020			
Cor Total	1.83	19				

Appendix B. ANOVA for Linear model for TTA

Source	Sum of squares	df	Mean square	*F*-value	*p*-value	
Model	1.13	3	0.3767	11.01	0.0004	significant
A-A	0.0005	1	0.0005	0.0142	0.9067	
B-B	0.0113	1	0.0113	0.3291	0.5742	
C-C	1.12	1	1.12	32.69	<0.0001	
Residual	0.5474	16	0.0342			
Lack of Fit	0.2447	11	0.0222	0.3676	0.9226	not significant
Pure Error	0.3026	5	0.0605			
Cor Total	1.68	19				

Appendix C. ANOVA for Linear model for viscosity

Source	Sum of squares	df	Mean square	*F*-value	*p*-value	
Model	0.9668	3	0.3223	4.10	0.0245	significant
A-A	0.0973	1	0.0973	1.24	0.2821	
B-B	0.6334	1	0.6334	8.07	0.0118	
C-C	0.2360	1	0.2360	3.01	0.1022	
Residual	1.26	16	0.0785			
Lack of Fit	0.7363	11	0.0669	0.6434	0.7485	not significant
Pure Error	0.5201	5	0.1040			

References

Alakali, J., Okonkwo, T. M., & Iordye, E. (2008). Effect of stabilizers on the physico-chemical and sensory attributes of thermized yoghurt. *African Journal of Biotechnology, 7*, 158–163.

Berhe, T., Ipsen, R., Seifu, E., Kurtu, M. Y., Eshetu, M., & Hansen, E. B. (2018). Comparison of the acidification activities of commercial starter cultures in camel and bovine milk. *LWT, 89*, 123–127. https://doi.org/10.1016/j.lwt.2017.10.041

Bulca, S., Dumanoğlu, B., & Özdemir, Ö. (2019). A study on mixing camel milk with cow, sheep and goat milk in different proportions in yoghurt production. *Turkish Journal of Agriculture: Food Science and Technology, 7*, 2095–2102.

Eissa, E. A., Yagoub, A. E. A., Babiker, E. E., & Ahmed, I. M. (2011). Physicochemical, microbiological and sensory characteristics of yoghurt produced from camel milk during storage. *Electronic Journal of Environmental, Agricultural and Food Chemistry, 10*, 2305–2313.

El-gammal, O., saad, I., & Moussa, M. A. M. (2007). Improving the quality of yoghurt manuf actured from camel milk. *Journal of Food and Dairy Sciences, 32*(8), 6431–6442. https://doi.org/10.21608/jfds.2007.204638

Eze, C. M., Aremu, K. O., Alamu, E. O., & Okonkwo, T. M. (2021). Impact of type and level of stabilizers and fermentation period on the nutritional, microbiological, and sensory properties of short-set Yoghurt. *Food Science and Nutrition, 9*(10), 5477–5492. https://doi.org/10.1002/fsn3.2507

Farah, Z., & Rüegg, M. (1991). The creaming properties and size distribution of fat globules in camel milk. *Journal of Dairy Science, 74*(9), 2901–2904. https://doi.org/10.3168/jds.S0022-0302(91)78472-5

Galeboe, O., Seifu, E., & Sekwati-Monang, B. (2018). *Production of camel milk yoghurt: Physicochemical and microbiological quality and consumer acceptability*. doi:10.7455/ijfs/7.2.2018.a5.

Gassem, M. A., & Abu-Tarboush, H. M. (2000). Lactic acid production by Lactobacillus delbrueckii spp. Bulgaricus ssp. Bulgaricus in Camel's and Cow's whey. *Milk Science International- Milchwissenschaft, 55*, 374–378.

Habte, H., & Emire, S. (2016). Optimization of the processing conditions of stirred yoghurt from camel milk using linear programming technique. *Food Science and Quality Management, 56*, 33–38.

Hashim, I. B., Khalil, A. H., & Habib, H. (2009). Quality and acceptability of a set-type yogurt made from camel milk. *Journal of Dairy Science, 92*(3), 857–862. https://doi.org/10.3168/jds.2008-1408

Ibrahem, S. A., & El Zubeir, I. E. (2016). Processing, composition and sensory characteristic of yoghurt made from camel milk and camel–sheep milk mixtures. *Small Ruminant Research, 136*, 109–112.

Ibrahim, A., & Khalifa, S. (2015a). Improve sensory quality and textural properties of fermented camel's milk by fortified with dietary fiber. *Journal of American Science, 1111*, 42–54.

Ibrahim, A., & Khalifa, S. (2015b). The effects of various stabilizers on physiochemical properties of camel milk yoghurt. *Journal of American Science, 11*, 15–24.

Isanga, J., & Zhang, G. (2009). Production and evaluation of some physicochemical parameters of peanut milk yoghurt. *LWT - Food Science and Technology, 42*(6), 1132–1138. https://doi.org/10.1016/j.lwt.2009.01.014

Karaman, A., Akgül, F., Ogut, S., Seçilmiş Canbay, H., & Alvarez, V. (2021). Gross composition of raw camel's milk produced in Turkey. *Food Science and Technology*. https://doi.org/10.1590/fst.59820

Kolapo, A. (2007). Effect of different stabilizers on acceptability and shelf-stability of soy-yoghurt. *African Journal of Biotechnology, 6*, 1000–1003.

Krisnaningsih, A., Purwadi, P., Evanuarini, H., & Rosyidi, D. (2019). The effect of incubation time to the physicochemical and microbial properties of yoghurt with local taro (Colocasia Esculenta (L.) Schott) starch as stabilizer. *Current Research in Nutrition and Food Science Journal, 7*, 547–554. https://doi.org/10.12944/CRNFSJ.7.2.23

Machan, S. N., Agwata, J. F., & Oguge, N. O. (2022). Aspects of the sustainability of the camel milk value chain and its regulatory framework in Isiolo County. *Northern Kenya, 11*(2), 199–216.

Mishra, S., & Rai, T. (2006). Morphology and functional properties of corn, potato and tapioca starches. *Food Hydrocolloids, 20*, 557–566. https://doi.org/10.1016/j.foodhyd.2005.01.001

Moss, M. O., & Adams, M. R. (2008). *Food microbiology* (3rd ed.). Cambridge: The Royal Society of Chemistry.

Muliro, P. S., Shalo, P. L., & Kutima, P. M. (2013). Optimization of camel milk coagulum formation and consumer preference. *African Journal of Food Science and Technology, 4* (8), 176–181.

Mustafa, E., Tyfor, B., & Tabidi, M. (2015). The effect of mixing different percentages of cow milk on the physiochemical characteristics of camel milk yoghurt and the sensory evaluation of yoghurt. *World Journal of Pharmacy and Pharmaceutical Sciences, 4*, 180–190.

Obi, C., Vu, O., & Cp, M. (2018). *Yoghurt production from powdered milk using mixed lactic acid bacteria starter cultures*. doi:10.21276/sjpm.2016.1.2.3.

Oselu, S., Ebere, R., Huka, G., Musalia, L., Marete, E., Mathara, J. M., Mwobobia, F., & Arimi, J. M. (2022). Production and characterisation of camel milk yoghurt containing different types of stabilising agents. *Heliyon, 8*(11), e11816. https://doi.org/10.1016/j.heliyon.2022.e11816

Ramasubramanian, L., Restuccia, C., & Deeth, H. C. (2008). Effect of calcium on the physical properties of stirred probiotic yogurt. *Journal of Dairy Science, 91*(11), 4164–4175. https://doi.org/10.3168/jds.2008-1354

Renan, M., Guyomarc'h, F., Arnoult-Delest, V., Pâquet, D., Brulé, G., & Famelart, M.-H. (2009). Rheological properties of stirred yoghurt as affected by gel pH on stirring, storage temperature and pH changes after stirring. *International Dairy Journal, 19*(3), 142–148. https://doi.org/10.1016/j.idairyj.2008.09.007

Savaiano, D. (2014). Lactose digestion from yogurt: Mechanism and relevance. *The American Journal of Clinical Nutrition, 99*. https://doi.org/10.3945/ajcn.113.073023

Szajnar, K., Znamirowska, A., Kalicka, D., & Zaguła, G. (2016). Fortification of yoghurts with calcium compounds. *Journal of Elementology, 22*(3), 869–879.

Weerathilake, W., Dissanayake, D., Ruwanmali, J., & Munasinghe, M. (2014). The evolution, processing, varieties and health benefits of yogurt. *International Journal of Scientific and Research Publications, 4*, 1–10.

Zainoldin, K., & Hj Baba, A. S. (2009). The effect of *Hylocereus polyrhizus* and *Hylocereus undatus* on physicochemical, proteolysis, and antioxidant activity in yogurt. *World Academy of Science, Engineering and Technology, 60*, 361–366.