Development and Optimization of Cultured Goat Cream Butter

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ABSTRACT: A central composite design 2^2 + star based on response surface methodology was used for development and optimization of a cultured goat cream butter formulation (cultured). The goat milk cream was inoculated with freeze-dried mesophilic aromatic lactic cultures and showed an increase in acidity and a decrease in lactose content when the concentration of lactic cultures was increased. An optimized temperature of 28°C was chosen for fast acid production in the goat milk cream. The lactic culture concentration significantly affected flavor, sensory texture, and overall quality, but the fermentation time did not produce significant changes in sensory texture and overall quality. The optimal values of the fermentation process were an inoculum dosage of 8.8 U/100 L and a fermentation time of 7 h at 28°C. This cultured formulation achieved optimal sensory quality in the attributes appearance, flavor, texture, and overall quality. At refrigerator temperature (4°C) the cultured formulation behaved as a solid and lacked spreadability, whereas it had ideal spreadability at 15°C when the solid fat content (SFC) was around 18.0%. At room temperature (18–25°C) the SFC was between 11 and 8%, respectively.

KEY WORDS: Central composite design, cultured goat cream butter, development, DSC, fermentation, optimization, response surface methodology (RSM), solid fat content (SFC), texture.

Exploitation of goat herds in barren zones is important to obtain useful products such as milk, cheese, meat, and leather. A major proportion of Chile's rural population depends directly on the exploitation of these herds, because this productive activity leads to higher economic stability than dry-land cultivation.

Goat milk deserves growing interest, with an annual worldwide production of nearly 10.6 million metric tons, in third place after cow milk and buffalo milk. Chilean production corresponds to 0.1% of the worldwide production (1). The nutritional value of goat's milk is similar to cow's milk, and it is recommended for children with an intolerance to cow's milk because it has a lower content of casein αs_1. This allows faster digestion, as the protein is more easily attacked by stomach proteases. On the other hand, goat's milk has a higher short-chain FA content (10 to 15 vs. 5 to 9%) and a smaller fat droplet size (1.99 vs. 3.52 μm) than cow's milk. This allows better action of stomach lipases; therefore, this milk is more digestible (2).

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From an industrial point of view, goat's milk is directed mainly to cheese manufacture, and, in a very small proportion, to other dairy products such as yogurt, butter, and milk powder. The latter is produced in the United States and South Africa for infant feeding.

Goat's milk presents several important characteristics in butter manufacture. It has a higher fat content of different composition and structure than that of cow's milk fat. The predominantly short-chain FA such as caproic, caprilic, and capric impart a characteristic odor, flavor, and texture to the goat's milk butter. On the other hand, goat's milk butter has a characteristic white color due to absence of carotenoids (2).

Cultured cream butter, unlike sweet cream butter, is manufactured with acidified cream by means of addition of lactic cultures. The advantages over sweet cream butter are better aroma, higher yield, and smaller risk of contamination after the heat treatment. Consumption of these microorganisms in sufficient amounts could exert specific biological activity in the body with beneficial health effects, acting as a defense barrier against possible gastrointestinal diseases (3).

The objectives of this study were (i) to determine the temperature, culture concentration, and fermentation time required to produce optimal sensory quality of cultured goat cream butter and (ii) to characterize physical properties of the optimal cultured goat cream butter produced.

EXPERIMENTAL PROCEDURES

Source materials. Goat's milk (400 L) was purchased for the analyses from Larapinto Co. (Santiago, Chile) between July and September, the winter months in Chile. A 300-L batch from September was used for the experimental design. Goat cream was inoculated with Freeze Dried Mesophilic Aromatic Culture from Chr. Hansen's Laboratories A/S (Horsholm, Denmark), DVS-50 FER LACTICO LD`CH-N-22 CH-100101 50 U, which is a multiple mixed-strain culture containing *Lactococcus lactis* subsp. *cremoris*, *Lactococcus lactis* subsp. *lactis*, *Leuconostoc mesenteroides* subsp. *cremoris,* and *Lactococcus lactis* subsp. *diacetylactis* (Dilaco S.A., Santiago, Chile). The culture concentration was expressed as U/100 L of cream, where 1 U/100 L indicates an average cell population, as colony-forming units (cfu), of $1.523 \cdot 10^5$ cfu/mL of cream. All chemicals were purchased from Merck Chemical Co. (Santiago, Chile). Cow's milk butter (Soprole S.A., Santiago, Chile) and margarine (Coprona S.A., Santiago, Chile) were purchased at a local supermarket.

Cultured cream preparation. Milk was received at the laboratory facilities, filtered, preheated (40ºC), and skimmed (electric separator Elecrem 1, 80 L/h; Elecrem, Vanves, France) to obtain a standardized cream with a fat content of ≥35%. The cream obtained was pasteurized in covered beakers (90°C for 5 min) and cooled to fermentation temperature.

Influence of temperature and inoculum dosage in the cultured process. Goat cream was inoculated (dosages of 10, 20, 30, 35, 45, 51 U/100 L) and incubated (20, 24, 28, and 36°C) for 15 h. This was the time considered necessary to allow all the formulations to reach a pH of 4.5 and an acidity of 0.6% expressed as lactic acid. Acidity measurements were conducted in duplicate, and pH was monitored at 1 h intervals. Lactic culture evolution, measured as lactic acid, was modeled using the Gompertz equation (4).

Experimental design. The experiments were performed with a central composite design 2^2 + star of nine experiments (5–7). The independent variables considered were lactic culture concentration from 8.8 up to 51 U/100 L and fermentation time from 5.6 up to 8.4 h. Three repetitions were conducted at low, medium, and high levels of the experimental design to estimate the experimental error (Table 1). Temperature was fixed at the optimal value, according to the results of the influence of temperature and inoculum dosage on the acidifying process. A noncultured goat cream butter was chosen as the control.

Cultured cream butter preparation. After pasteurization, cream was cooled rapidly to 8 ± 1°C, held for 2 h and heated to the fermentation temperature of 28 ± 1°C. After fermentation, with time and inoculum dosage set according to the experimental design (Table 1), the cultured cream was cooled rapidly to 10 ± 1°C to stop the fermentation. Churning was done immediately at constant speed in a churn (ELBA 30; Elecrem) with a cream capacity of 12 L, until particles formed. Butter particles were washed four times with distilled water at 10°C. Butter was worked out in the churn until moisture was evenly distributed. An amount of salt (Super Sal Lobos S.A., Santiago, Chile), 1% by weight of the total butter, was added and distributed homogeneously. Butter was packaged in polystyrene bags in 250-g portions and stored at 3°C for further analyses.

Variable optimization. Response surface methodology (RSM) was used. The response variable of the experimental design was sensory quality of cultured goat cream butter (Table 1). Twelve panelists with experience in sensory testing were selected from among the department personnel. Additional training was conducted during an 11-session training period (8). Panelists were familiarized with butter defects based on the International IDF Standard 99 (9). Attributes considered and their maximum scores, corresponding to least defects, were: appearance (20), odor (20), flavor (30), texture (30), and overall quality (sum of the partial scores). A noncultured goat cream butter was chosen as the control sample. A two-way ANOVA (panelists and assays) was conducted on the design responses for each attribute. The requirements for optimization were: significant differences among formulations ($P \leq 0.05$), but not among panelists. Multiple regression equations were fitted to the attributes that fulfilled this requirement, discarding nonsignificant terms, to obtain the response surfaces. A multiple response optimization was performed to optimize several responses simultaneously, maximizing a desirability function that ranged from 0 to 1. The Statgraphics Plus, version 4.0, software package was used for data analyses (Manugistics Inc., Rockville, MA).

Physicochemical data. The following parameters of the chemical composition of milk were determined according to Reference 10: acidity (AOAC Official Method 947.05), nonfat solids (AOAC Official Method 990.21), fat (IDF-ISO-AOAC Official Method 989.04), nitrogen (total) (IDF-ISO-AOAC Official Method 991.20), lactose (AOAC Official Method 930.28), ash (IDF-ISO-AOAC Official Method 945.46), and specific gravity (AOAC Official Method 925.22). Cream was also analyzed for lactic acid (AOAC Official Method 945.47), specific gravity (AOAC Official Method 925.22), nonfat solids

TABLE 1
Bidimensional Central Composite Design and Response Data of Cultured Goat Cream Butter

	Independent variables		Response variables							
Experiments	Culture concentration (U/100 L)	Time (h)	Appearance[a]	Odor[a]	Flavor[b]	Texture[b]	Overall quality[c]	Range of melting (°C)	Onset of melting (°C)	Hardness[d] (N/cm^2)
1[e]	15	6	17.2	18.1	27.3	26.1	88.6	–44.8 to 28.4	–30.9	3.21 ± 0.11
2	45	6	19.7	17.5	23.0	28.7	88.8	–40.4 to 40.2	–36.2	3.40 ± 0.13
3	15	8	16.2	17.5	23.8	26.8	84.3	–40.0 to 40.0	–33.7	3.49 ± 0.21
4[e]	45	8	16.9	18.6	25.0	23.8	84.3	–42.1 to 34.4	–14.7	3.34 ± 0.14
5[f]	8.8	7	18.5	16.3	26.7	27.3	88.8	–40.0 to 40.0	–14.1	3.57 ± 0.18
6	51.2	7	18.5	16.2	24.0	26.3	85.0	–41.6 to 36.7	–17.0	2.91 ± 0.11
7	30	5.6	14.7	18.7	24.7	20.3	78.3	–40.0 to 32.9	–8.5	4.02 ± 0.28
8	30	8.4	14.7	17.0	24.8	18.5	75.0	–40.0 to 40.0	–15.2	3.98 ± 0.10
9	30	7	15.8	16.7	22.5	22.5	77.5	–40.0 to 29.4	–14.1	3.12 ± 0.11
9	30	7	18.7	16.2	22.5	24.0	81.3	–40.0 to 29.0	–14.0	3.15 ± 0.14

[a]Maximum score 20.
[b]Maximum score 30.
[c]Sum of the partial scores with a maximum score of 100.
[d]Values are reported as mean ± 95% confidence interval.
[e]Values are reported as means of two replicates.
[f]Optimal cultured goat cream butter (cultured) formulation.

(AOAC Official Method 990.21), fat (IDF-ISO-AOAC Official Method 920.111), nitrogen (total) (Official Method 920.109), lactose (AOAC Official Method 920.110), and ash (AOAC Official Method 920.108). Milk and cream pH were measured using a Wissenschaftlich-Technische Werkstätten GmbH, pH537 (Weilheim, Germany) instrument. Finally, the physical and chemical composition of butter was determined with respect to acid value (IDF-ISO-AOAC Official Method 969.17), refractive index (IDF-ISO-AOAC Official Method 969.18), iodine value (AOAC Official Method 933.20), solids (total) (IDF-ISO-AOAC Official Method 920.107), fat (IDF-ISO-AOAC Official Method 989.04), and moisture (IDF-ISO-AOAC Official Method 920.116) (10).

Solid fat content (*SFC*) *by DSC.* Calorimetric evaluations of melting behavior on cultured goat cream butter formulations were performed in a PerkinElmer differential scanning calorimeter (PE DSC 7; Norwalk, CT). Samples (9–10 mg) were loaded in hermetically sealed aluminum pans. All samples were tempered at 5°C for 24 h prior to measurements. DSC analyses were performed from 20 to –45°C and from –45 to 60°C at a scan rate of 5°C/min using an empty pan as the reference. Thermograms were analyzed by onset and temperature range of melting (°C) (11). Partial area integration at different temperatures under the endotherm corresponding to fusion curve was used for determination of the SFC. Data analysis was performed with the DSC software.

Textural properties. A constant-speed compression test was used to evaluate texture. Hardness was determined from a stress-distance curve obtained from a Universal Testing Machine (LR-5K; Lloyd Instruments Limited, Hampshire, United Kingdom). The experimental procedure presented earlier (12) was followed, except that the test was carried out at 10°C. The rupture tension was calculated by dividing the maximum force (maximum peak) by surface sample area (13,14).

Statistical analysis. Physical and chemical analyses were performed in triplicate. The 95% confidence intervals of each property and each analysis were calculated, taking into account the number of replications and considering the SD of each sample.

RESULTS AND DISCUSSION

Acidity. Goat's milk collected for this study was high in acidity (Table 2), which is associated with a high casein content of the milk (2). Casein content depends on the lactation period and increases at the end of the lactation (2). The cream was lower in acidity than milk (Table 2) because of its higher fat content and lower casein content, minerals, and organic acids as well as the secondary reactions caused by phosphates (2).

pH value. The pH of goat milk was within the normal range of 6.3 to 6.7 determined for goat's milk by Luquet *et al.* (2) (Table 2). Previous experiments indicated that goat's milk with a pH value below 6.5 or an acidity over 20 mL 0.1 N NaOH/100 mL is not suitable for butter manufacture, as it coagulates during pasteurization.

Specific gravity. The specific gravity of goat's milk was within the reference range of 1.026 to 1.042 (2). The specific gravity of goat's milk cream was lower than the milk, owing to its higher fat content (Table 2).

Fat content. Great variability in goat's milk fat content was observed from July to September (Table 2). Several studies have shown that fat content depends on genetic factors, production levels, lactation period, climatic factors, milking technique, and feed composition (1,3). Feeding high-fiber forage to goats could have caused the high fat content of the goat's milk in this study.

Influence of temperature and inoculum dosage in the culturing process. Effects of temperature on acidity in cream cultured with an inoculum of 20 U/100 L is shown in Figure 1A. Fermentation temperature had a significant effect ($P \leq 0.05$) on growth of lactic acid bacteria. The highest acidity increase, after 6 h of incubation, was obtained at 28°C, compared with the results obtained at 20, 24, and 36°C. The time to reach a pH of 4.5 or an acidity of 0.6%, expressed as lactic acid, in goat's milk cream was considered. Subsequently, the temperature of 28°C was chosen as the optimal value for fast acid production. At 20°C no significant lactic acid production was observed, as this fermentation temperature inhibits the growth of the freeze-dried mesophilic aromatic culture. Figure 1B shows the effects

TABLE 2
Physical and Chemical Analyses of Goat's Milk, Cream, and Optimal Cultured Goat Cream Butter[a]

Analyses	Milk[b]	Cream	Cultured[c]
Acidity	18.6 ± 0.4 to 20.0 ± 1.2[d]	13.5 ± 1.2 to 17.6 ± 1.2[d]	0.85 ± 0.07[e]
pH	6.55 ± 0.05 to 6.90 ± 0.05	6.62 ± 0.05 to 6.93 ± 0.05	ND
Specific gravity	1.028 ± 0.002 to 1.032 ± 0.002	0.962 ± 0.001 to 0.990 ± 0.001	ND
Nonfat solids (g/L)	92.6 ± 0.7 to 102.0 ± 0.5	25.1 ± 0.5 to 26.3 ± 0.5	41.5 ± 0.3
Fat (% w/w)	4.1 ± 0.5 to 7.2 ± 0.5	45.7 ± 0.5 to 47.3 ± 0.5	82.0 ± 0.3
Protein, N·6.38 (% w/w)	4.47 ± 0.09	0.90 ± 0.03	ND
Lactose (% w/w)	4.83 ± 0.18	3.83 ± 0.05	ND
Ash (% w/w)	0.87 ± 0.07	0.47 ± 0.01	ND
Moisture (% w/w)	84.6 ± 0.2	48.6 ± 0.5	13.9 ± 0.3
Refractive index (n_D^{40})	ND	ND	1.4580 ± 0.0000

[a]Values are reported as mean ± 95% confidence interval.
[b]Milk received between July and September from 200 goats in the sixth week lactation.
[c]Optimal cultured goat cream butter (cultured) formulation (experiment number 5 from Table 1).
[d]mL NaOH 0.1 N/100 mL of sample.
[e]mg KOH/g of sample. ND, not determined.

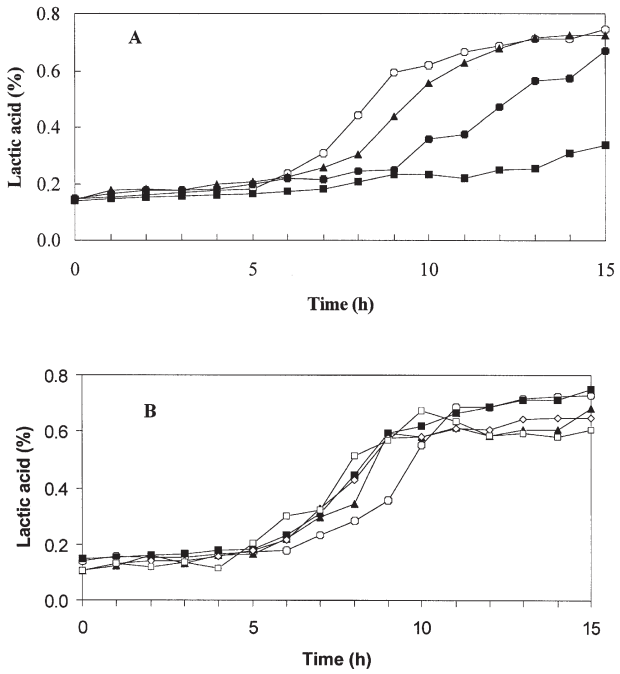

FIG. 1. (A) Lactic acid evolution of goat's milk fermented cream with an inoculum dosage of 20 U/100 L at different temperatures as a function of time: 20°C (■), 24°C (●), 28°C (○), 36°C (▲). (B) Lactic acid evolution of goat's milk fermented cream at 28°C at different inoculum dosages as a function of time: 10 U/100 L (○), 20 U/100 L (■), 30 U/100 L (▲), 35 U/100 L (◇), 51 U/100 L (□).

of inoculum dosage on acidity obtained at 28°C. Bacterial growth modeled by the Gompertz equation fit adequately only for inoculum dosages of 10, 20, 30, 35, and 45 U/100 L ($R^2 >$ 78%), whereas an inoculum dosage of 51 U/100 L showed R^2 = 63%. Inoculum dosages were not significantly different from each other ($P > 0.05$). As these results were not satisfactory for use in choosing the best inoculum dosage, this parameter was included as an independent variable in the experimental design.

Optimization of the fermentation process. Mean values for the sensory attributes of appearance, odor, flavor, texture, and overall quality of the experimental design formulations are presented in Table 1. After stepwise elimination of nonsignificant effects, response-predicting models were obtained (Table 3). Figure 2 shows the response surfaces for the sensory attributes as a function of the processing variables. The lactic culture concentration significantly affected flavor, texture, and overall quality ($P \leq 0.05$), but the fermentation time significantly affected appearance and flavor. An inoculum dosage of 8.8 U/100 L and a fermentation time of 7 h were the combination of factor levels that maximized texture and overall quality, whereas the combination of 30.4 U/100 L and 6.8 h optimized appearance, and the combination of 8.8 U/100 L and 5.6 h optimized flavor. The sensory attribute odor was not considered as an optimizing response variable, as it presented significant differences among panelists ($P \leq 0.05$) but not among formulations ($P > 0.05$). A combined response surface of the optimizing response variables was obtained with the responses appearance, texture, and flavor (Fig. 2E), which shows the combination of factors at which an optimum was achieved. A maximum desirability of 0.91 (range 0 to 1) was obtained in Experiment 5 (Table 1). Therefore, processing conditions for the optimal cultured goat cream butter (cultured) formulation were: inoculum dosage of 8.8 U/100L and fermentation time of 7 h.

Fermentation effect on SFC of goat cream butter. The SFC profiles as a function of temperature for noncultured goat cream butter (control) and cultured goat cream butter of the experimental design formulations (Table 1) are shown in Figure 3. Some formulations were omitted, as they followed the same SFC trend. All formulations showed SFC nonlinear profiles, and the rate of SFC evolution was dependent on lactic culture concentration ($P \leq 0.05$), whereas the fermentation time did not produce significant changes ($P > 0.05$) (Fig. 3; Table 3).

The melting behavior of cultured goat cream butter was characterized by the temperature range of melting and the onset

TABLE 3
Response Equations with Regression Coefficients, Significance, *R*-squared Statistic, and SE[a]

Terms	Appearance	Flavor	Texture	Overall quality	SFC (20°C) (%)	Hardness (N/cm^2)
Constant	−48.6	101.4	34.7	100.5	16.40	66.9
X_1: Culture	—	−1.1	−0.8	−1.4	−1.05	—
X_2: Time	19.5	−17.7	—	—	—	−16.0
X_1	—	0.01	0.01	0.02	0.018	—
X_2^2	−1.4	1.1	—	—	—	1.17
X_1X_2	—	0.1	—	—	—	—
R^2, (%)[b]	48.4	97.7	56.2	64.1	61.3	66.2
SE[c]	1.42	0.37	1.48	3.19	2.61	0.69
MAE[d]	0.80	0.17	1.75	2.37	2.2	0.47
DW[e]	>1.4	>1.4	>1.4	>1.4	>1.4	>1.4
P (panelists)	0.19	0.06	0.05	0.06		
P (formulations)	0.003	0.02	0.00	0.001		

[a]Terms significant at $P \leq 0.05$ (if the quadratic or an interaction effect of any independent variable is significant, the term corresponding to the linear effect is included in the equation, although it is not significant).
[b]*R*-squared statistic indicates that the model used explains the variability.
[c]SE of the estimate show the SD of the residuals.
[d]The mean absolute error (MAE) is the average value of the residuals.
[e]The Durbin-Watson (DW) statistic tests the residuals to determine whether there is any significant correlation based on the order in which they occur in the data file.

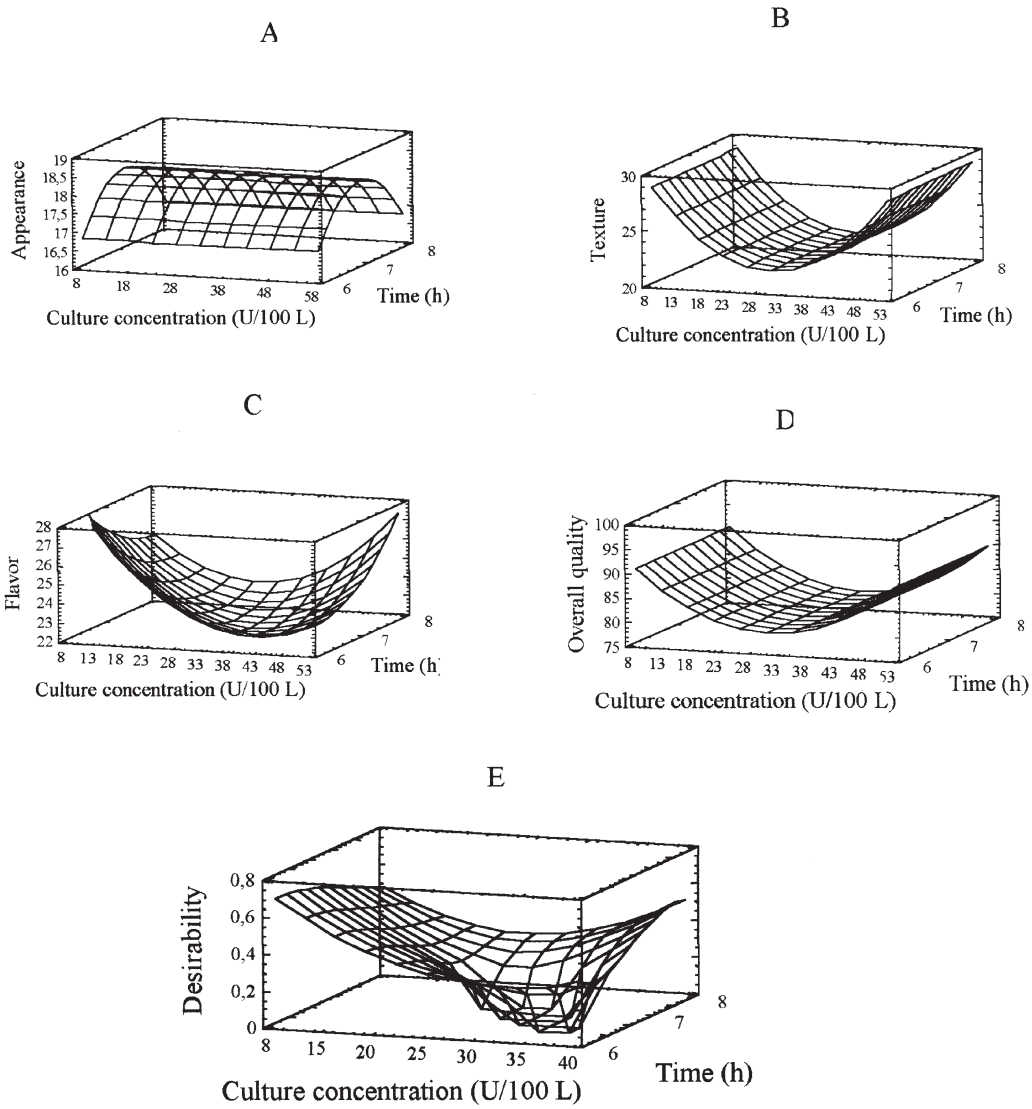

FIG. 2. Influence of culture concentration and time on sensory attributes of cultured goat cream butter. (A) Appearance response surface; (B) texture response surface; (C) flavor response surface; (D) overall quality response surface; (E) multiple response optimization.

of melting (DSC thermograms not shown). Butterfat (cow's milk fat) contains numerous TAG with a melting range from –40 to 40°C (11), whereas our control sample exhibited a melting range from –43 to 34°C and an onset of melting temperature of –30.6°C. Relative to the control, the fermentation increased the melting range of the optimal cultured goat cream butter from –40 to 40°C and the onset of melting to –14.1°C (Table 1).

The cultured goat cream butter formulations had a SFC between 96 and 100% at –30°C that decreased nonlinearly until no solid fat was observed between 25 and 37°C (Fig. 3). The optimal cultured goat cream butter was completely melted at 37°C (Fig. 3). Rousseau *et al.* (11) found that the butterfat had an SFC of 49% at 5°C and was completely melted at 40°C. The SFC profiles of the formulations and the optimal cultured goat cream butter differed from those of the butterfat owing to the nature of FA composition and fatty distribution within the TAG group. Butterfat is a mixture of 400 different FA, 25% of which are short-chain and 45% are long-chain saturates (11). The noncultured goat cream butter (control) presented higher caproic (C_6), caprylic (C_8), and capric (C_{10}) short-chain FA proportions than butterfat (3.1; 3.1; 6.4% vs. 2.7; 1.8; 3.5%).

The SFC profile for the optimal cultured goat cream butter was significantly different from the control. These differences may be attributed to a large proportion of TAG that melt at lower temperatures in the control formulation. Experiments 3 and 6 (15 U/100 L/8 h and 51.2 U/100 L/7 h, respectively) (Table 1) were highest in SFC between 20 and 35°C (Fig. 3).

At temperatures of 0 and 4°C, SFC values of the formulations (Table 1) ranged between 52.9–35.9 and 44.4–29.9%, respectively, and were dominated by solid high- and medium-m.p. TAG. The optimal cultured goat cream butter (Experiment

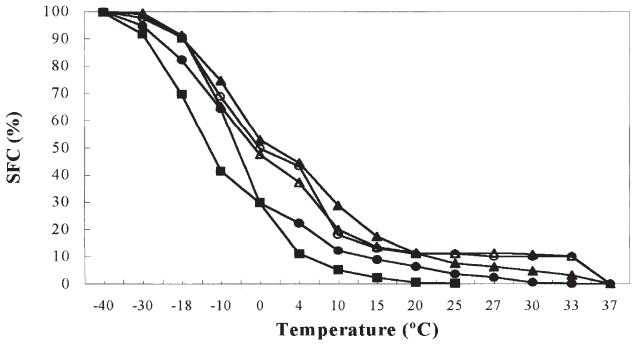

FIG. 3. Solid fat content (SFC) evolution of noncultured goat cream butter (control), optimal cultured goat cream butter (cultured), and cultured goat cream butter formulations as a function of temperature (°C): control 0 U/0 L/0 h (●), cultured 8.8 U/100 L/7 h (▲), 15 U/100 L/8 h (○), 30 U/100 L/7 h (■), 51.2 U/100 L/7 h (△).

5, Table 1; Fig. 3) presented the major SFC proportion at 4°C, but all formulations had a limited plastic range and behaved as a solid similar to butter. At 21–25°C, formulations 3 and 6 and the optimal cultured goat cream butter (Table 1; Fig. 3) were highest in SFC, from 7 to 14%, and contained mainly high-m.p. TAG. Robinson (15) reported that the level of solid fat in most butters is too high for easy spreading when cold. Although butter is normally sufficiently plastic to spread at 15°C, when less than 40% of the fat is solid, easy spreading characteristics are only achieved at solid fat levels of 20–30%. The optimal cultured goat cream butter exhibited an ideal spreadability at 15°C when its SFC was around 18.0%, determined from the SFC profile by DSC (Fig. 3). These results agree with those found for a cow's milk butter (Soprole S.A., Santiago, Chile) with ideal spreadability at 15°C. Fermentation produced an optimal cultured goat cream butter with a SFC profile similar to cow's milk butter (Soprole S.A., Santiago, Chile), whereas the control SFC profile was always lower than that of the optimal cultured goat cream butter and was similar to a margarine (Coprona S.A., Santiago, Chile) (Fig. 3).

Textural parameter. The hardness of the formulations was significantly affected by fermentation time ($P \leq 0.05$), whereas the lactic culture concentration did not produce significant changes ($P > 0.05$) (Table 3). The hardness of the optimal cultured goat cream butter and the control were significantly different from one another ($P \leq 0.05$) (Table 1). The minimum breaking force was 3.12 ± 0.11 (N/cm^2) for Experiment 9 (30 U/100 L/7 h), showing the lowest value for hardness, highest moisture, lowest fat content, and lowest SFC from 4 to 25°C ($P \leq 0.05$) (Fig. 3). The optimal cultured goat cream butter hardness was 20% lower than butterfat and 24% higher than the control ($P \leq 0.05$).

ACKNOWLEDGMENTS

The authors express their gratitude to LANFOOD-IPICS (Red Latinoamericana de Investigación en Alimentos-International Programme in the Chemical Sciences) Sweden; CEPEDEQ (Centro de Estudio Para el Desarrollo de la Química) Faculty of Chemical and Pharmaceutical Sciences, University of Chile, Santiago, Chile; and Post-Graduate Grant PG034/98-DID, University of Chile.

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