Characterization of Queso Fresco during Storage at 4 and 10°C

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Abstract

Queso Fresco, a popular Hispanic cheese variety, was prepared and its chemical, rheological, textural, functional, and sensory aspects were evaluated during storage at 4 and 10°C to determine changes in quality. Decreases in lactose and pH levels were observed and attributed to activity by spoilage microorganisms. The appearance of volatile compounds derived from lipids indicated that lipolysis was taking place, and some proteolysis was also noted. Minor variations in texture profile, torsion, color, and melt analyses were seen throughout 8 wk of storage. No microstructural changes were observed. A consumer taste panel generally liked laboratory-made and two commercially-made cheeses, and could not distinguish one of the commercial samples from the laboratory sample. The results provide a basis for assessing the quality traits of Queso Fresco during storage.

Keywords: Queso Fresco, Rheology, Texture, Microstructure

1. Introduction

Queso Fresco, a rennet-set soft white cheese, is gaining popularity in the US. It is often eaten fresh, hence its name, but many consumers and retail outlets would like the option of refrigerating it for a few weeks. To do this, the characteristics of Queso Fresco have to be investigated over time at typical storage temperatures. Home refrigerators in the U.S. are usually maintained around 4°C, but a significant number are kept at 10°C, and the average in Europe is 6.7-7.0°C (Pouillot, Lubran, Cates, & Dennis, 2010). Warehouse storage and delicatessen dairy cases may also be above 4°C. Changes with time on textural properties previously reported for this variety compared 4°C storage for 1 and 8 d (Sandra, Stanford, & Meunier Goddick, 2004) and 4°C storage for 1 and 8 wk (Guo, Van Hekken, Tomasula, Shieh, & Tunick, 2011a). Earlier research on Queso Fresco in our laboratory compared rheology, texture, and microstructure of commercial samples made from raw and pasteurized milk (Tunick & Van Hekken, 2010). Queso Fresco made in our laboratory and containing 0-2.5% NaCl has been evaluated for color, melt, rheology, and microstructure (Guo et al., 2011a) and for microbial count and proteolysis (Guo, Van Hekken, Tomasula, Tunick, & Huo, 2011b). Volatile compound identification has not been reported for this variety.

Queso Fresco has a pH over 6.0 and is commonly milled before salting. It is characteristically a crumbly cheese (Hwang & Gunasekaran, 2001) and a non-melting cheese (Guo et al., 2011a). Sensory tests revealed that Hispanics and those familiar with Queso Fresco preferred samples with high NaCl and pH levels, and consumers who had little previous experience with Queso Fresco preferred low NaCl and pH levels (Clark, Warner, & Luedecke, 2001). Its acceptability relies in part on its color (bright white), texture, and structure (Van Hekken & Farkye, 2003). This paper describes the quality traits of Queso Fresco from starter-free, pasteurized, homogenized milk and stored for up to 8 wk at 4 and 10°C. The research was divided into two phases: in Phase I the main focus was on the functional properties of color and melt, and in Phase II the emphasis was on consumer sensory tests and effect of storage on protein profiles and volatile compounds.

2. Materials and Methods

2.1 Cheese preparation

Queso Fresco cheeses were manufactured in eight production runs in the Dairy & Functional Foods Research Unit laboratory. Locally-obtained milk was standardized to 3.5% fat and pasteurized at 72°C for 15 s. After two-stage homogenization at 6.9 and 3.4 MPa, 180 kg of milk containing 180 g of added $CaCl_2$ was adjusted to 32°C in a stainless steel vat. The milk was coagulated with chymosin (14 mL Chy-Max, Chr. Hansen, Milwaukee, WI, USA; diluted in 200 mL water) and cooked at 39°C for 30 min. Approximately one-third of the whey was drained and the curd was salted in three applications at 1.1% NaCl (w/w). The rest of the whey was drained and the curds were cooled to 21°C, finely milled into small (< 1 cm) pieces with a grinder (Bosch universal kitchen machine, Robert Bosch Hausgeräte, Dillingen, Germany), and hand-packed into molds for storage overnight at 4°C. Cheeses were removed from the molds the next day, sliced into three blocks, and vacuum packaged. Samples were stored for up to 8 wk at 4 or 10°C. Phase I cheeses consisted of Queso Frescos from the first five production runs, and Phase II cheeses were from the last three runs.

2.2 Composition

The following compositional analyses were run in triplicate: moisture (forced-draft oven, AOAC Official Method 948.12; AOAC International 1998), protein (EA1112 nitrogen analyzer, CE Elantech, Lakewood, NJ, USA; nitrogen result multiplied by 6.38), ash (heating in muffle furnace at 550°C for 16 h; AOAC Official Method 935.42; AOAC International 1998), lactose (YSI 2700 biochemistry analyzer, YSI, Yellow Springs, OH, USA), and pH (Orion model 611, Orion Research Corp., Cambridge, MA, USA). The following were run in duplicate: fat (Babcock method; Kosikowski & Mistry, 1997), NaCl (chloride titrator strip, Hach Co., Loveland, CO, USA, AOAC Official Method 971.19; AOAC International 1998), and titratable acidity (titration, AOAC Official Method 920.124; AOAC International 1998). Ash and titratable acidity were assayed on Phase II cheeses only.

2.3 Protein profiles

Protein profiles of Phase II cheeses were obtained by SDS-PAGE using the procedure of Van Hekken, Tunick, Tomasula, Molina Corral, and Gardea (2007) and Tunick, Van Hekken, Call, Molina Corral, and Gardea (2007). The PhastSystem (American Pharmacia Corp., Piscataway, NJ, USA) was used to separate proteins on 20% homogeneous gels. Gels were stained with Coomassie blue and scanned with a model 375A Personal Densitometer SI (Molecular Dynamics, Sunnyvale, CA, USA). Protein distributions were calculated with ImageQuant software version 4.2 (Molecular Dynamics). Lanes were analyzed in duplicate with bands being identified as α_{s1}-, α_{s2}-, β-, and para-κ-caseins, and minor whey proteins. Casein fragments were grouped into molecular mass ranges of 22, 22-18.5, 18-15, and <14 kDa.

2.4 Volatile compounds

In a preliminary study, volatile compounds in Phase II cheeses were identified qualitatively by GC-MS. Samples were removed from a -80°C freezer and a 5-g portion was finely diced and sealed in a 20-mL glass vial. The vial was incubated at 60°C for 10 min, and a SPME fiber (50/30 µm DVB/Carboxen/PDMS Stableflex, Supelco, Bellefonte, PA, USA) absorbed volatiles from the headspace at 60°C for 30 min. The sample was desorbed for 5 min into a 30 m x 0.250 cm ID column (Agilent Technologies, Wilmington, DE, USA) inside a 7890A GC equipped with a 5975C MS detector (Agilent). The injector temperature was 250°C and the splitless flow was 1 mL min^{-1} ultrapure He. The column temperature was held at 40°C for 10 min, ramped at 5°C min^{-1} to 225°C, and held for 5 min.

2.5 Texture

Texture profile analysis (TPA) was performed as previously described (Tunick & Van Hekken, 2002). Four cylinders measuring 14 mm diameter and 14 mm height were cut from the samples and compressed twice by 75% in a Sintech 1/G universal testing machine (MTS Systems, Eden Prairie, MN, USA) operating at a crosshead speed of 100 mm min^{-1}.

2.6 Rheology

Torsion gelometry and SAOSA were conducted as previously described (Tunick & Van Hekken, 2002). Torsion analyses were performed using a torsion gelometer (Gel Consultants, Raleigh, NC, USA) operating at 2.5 rpm. Four plugs were bored from each sample, milled to a capstan shape, and twisted until fracture. SAOSA was performed using an AR-2000 rheometer (TA Instruments, New Castle, DE, USA) with parallel aluminum plates. Three disks measuring 25 mm in diameter and 4 mm thick were used. Strain sweeps were run to determine the linear viscoelastic range and frequency sweeps were then performed from 1 to 100 rad s^{-1} at 0.8% strain. Data for elastic or storage modulus (G′) and viscous or loss modulus (G″) were obtained; values at 10 rad s^{-1} (1.6 Hz) are reported.

2.7 Color and melt

Color and melt properties were analyzed on Phase I cheeses based on the procedure described by Olson, Van Hekken, Tunick, Soryal, and Zeng (2007) as modified by Guo et al. (2011a). Briefly, six disks (5 mm thick, 38 mm in diameter) were prepared from each sample and initial color values for L*, a*, and b* were measured using a Hunter Lab ColorQuest XE 2382 colorimetric spectrophotometer (Hunter Associates Laboratory, Reston, VA, USA). Four measurements for each disk were made. Three disks were heated at 232°C for 5 min or at 130°C for 30 min. After cooling, color measurements were collected again and used to calculate total color change (ΔE), hue angle, and color saturation or chroma.

Meltability was determined in triplicate using the Schreiber Melt Test as described by Kosikowski and Mistry (1997). The extent of melting was measured on the disks that were heated to 232°C for 5 min and used to collect color data.

2.8 Microscopy

The microstructure was examined with scanning electron microscopy (SEM) as previously described (Tunick, Van Hekken, Cooke, Smith, & Malin, 2000). Cubes measuring about 5 mm on a side were cut from the interior of the cheese and fixed in glutaraldehyde. They were then dehydrated, defatted in a graded series of ethanol solutions, freeze-fractured, critical-point dried, and imaged in a Quanta 200 field emission gun SEM (FEI Co., Hillsboro, OR, USA) operated in the high vacuum, secondary electron imaging mode.

2.9 Sensory analysis

Hedonic, difference, and ranking evaluations were conducted on Phase II cheeses to compare the flavor and overall acceptance of laboratory-made Queso Frescos to commercial samples. Three cheeses were tested by an untrained consumer taste panel in booths on the same day using protocols for a large group (over 50 people) established by Meilgaard, Civille, and Carr (1999). The laboratory cheeses were evaluated 8-10 d after manufacture, following testing by an independent certified laboratory to ensure their microbial safety. Two commercially available 5-kg wheels of Queso Fresco were obtained. One sample, designated C-1, was received directly from the manufacturer < 24 h after it was made, and within 24 h of the manufacture of the laboratory cheese. Sample C-2 was obtained from a local distributor and estimated from its sell-by date to be 14-21 d old. The morning of the taste panel, cheese were removed from their packaging, cut into 2.5 cm^3 cubes, placed in 3-oz (84 mL) coded, lidded soufflé cups, and allowed to warm to 20°C. Sixty-five panelists were obtained in-house and received unsalted crackers and distilled water to cleanse their palates between samples.

In hedonic tests, samples were graded on a nine-point scale where 1 was "dislike extremely" and 9 was "like extremely." Triangle tests were used as difference tests; panelists tasted three cheeses, two of which were the same, and asked to identify the different one. In ranking tests, panelists tasted all three samples and ranked them by preference. Results are reported as raw numbers in accordance with Meilgaard et al. (1999).

2.10 Statistics

Statistical analyses were performed by analysis of variance with mean separation using the LSD technique (SAS 2004). Differences are described as significant when $P < 0.05$.

3. Results and Discussion

3.1 Composition

The composition of all samples was similar to Queso Frescos containing 2.5% NaCl that were prepared in earlier studies (Guo et al., 2011a, 2011b). The protein and lactose content of the Phase II cheeses were lower than those of Phase I and the NaCl content was higher (Tables 1 and 2). The fat, protein, and ash did not vary significantly over the 8 wk. The NaCl values were virtually identical for 4 and 10°C at each storage time, and the values significantly decreased with aging. Although the moisture levels were unchanged in the 4°C samples, all of the cheeses exhibited loss of whey during storage, and it is probable that some of the NaCl was dissolved in the lost whey.

The pH decreased and the lactose content and titratable acidity increased in the 10°C samples during storage. These results indicate that microorganisms were breaking down lactose and generating lactic acid at 10°C, but that this activity was insignificant at 4°C. The pH was above 6.0 in all of the samples.

3.2 Protein profiles

SDS-PAGE of Phase II cheeses revealed that α_{s1}- and β-caseins decreased and casein fragments increased with storage (Table 3). Chymosin cleaves α_{s1}-, β-, and κ-caseins, and plasmin, an indigenous milk proteinase, hydrolyses α_{s1}-, α_{s2}-, and β-caseins (McSweeney, 2004). Over the 8 wk, the α_{s1}-casein decreased by one-fourth in the 4°C cheeses and by one-third in the 10°C cheeses. The levels of β-casein during storage went down by two-fifths at 4°C and by a half at 10°C. Similar results were reported previously (Guo et al., 2011b). Since no starter culture was used, the increased breakdown of casein at 10°C was apparently due to spoilage microbes introduced by contamination during processing. In the earlier study on Queso Fresco, which used the same facilities and procedures, bacteria found in the cheeses were identified as typical spoilage organisms found in dairy products: *Pseudomonas mandeli, Pseudomonas putida, Paenibacillus polymyxa,* and *Microbacterium oxydan* (Guo et al., 2011b). *Microbacterium* spp. is highly proteolytic (Hantsis-Zacharov & Halpern, 2007), and may have hydrolyzed the α_{s1}- and β-caseins.

3.3 Volatile compounds

GC-MS of the Phase II cheeses showed that a number of volatile compounds were generated during storage. Nonalactone and the methyl ketones 2-heptanone and 2-nonanone were noted at each storage time, and δ-dodecalactone appeared at 4 and 8 wk. The 10°C samples tended to contain more of these. The alcohols 3-methyl-1-butanol, phenyl ethyl alcohol, and 2,3-butanediol were present at 8 wk, and they were detected in the 10°C samples after 4 wk. The aldehydes pentanal, hexanal, and heptanal were present in the cheeses at 1 and 4 wk only, and presumably degraded into smaller compounds over the final 4 wk. Phenylacetaldehyde and 3-methyl butanal were present after 4 and 8 wk in the 10°C cheeses and after 8 wk in the 4°C samples. Nonanal and decanal appeared in every sample at every storage time. Acetic acid was observed at 4 and 8 wk.

Many of the volatile fatty acids normally found in cheese were also detected. Octanoic, decanoic, and dodecanoic acids were found throughout. An ester of propionic acid was also observed throughout, and nonanoic acid was seen at 8 wk, but butanoic and hexanoic acids were not observed. These results indicate that lipolysis was occurring. The major products of lipolysis and fatty acid catabolism include methyl ketones and secondary alcohols from β-ketoacid breakdown, lactones from hydroxyacid degradation, aldehydes from unsaturated fatty acid cleavage, and free fatty acids (Le Quéré & Molimard, 2002). All of these classes of compounds appeared in the samples. The cheesemilk was pasteurized, which should have inactivated lipolytic enzymes that may have been present, and starter culture and lipase were not added, so the lipolysis may have arisen from either the chymosin or from spoilage microorganisms. Lipolytic activity has not been reported for the brand of chymosin used in this study, implying that spoilage microbes are responsible. *Pseudomonas* spp. are known to have lipolytic activity in dairy products (Hantsis-Zacharov & Halpern, 2007), and it is possible that these microorganisms were responsible for products from lipid degradation.

3.4 TPA

Hardness is the amount of force required to compress a specimen, and cohesiveness is the ratio of the force-time areas from the two compressions. Hardness values were between 12 and 15 N for all of the samples (Tables 4 and 5), which was slightly higher than the 9.4-10.7 N range observed in a previous study (Guo et al., 2011a) but was low compared with other cheeses. For example, hardness values for fresh Cheddar, Gouda, and Mozzarella are 47, 77, and 68 N, respectively (Tunick & Van Hekken, 2002). The cohesiveness was between 0.13 and 0.21, in contrast to 0.21, 0.28, and 0.41 for fresh Cheddar, Gouda, and Mozzarella. Queso Fresco is thus quite compressible and not very cohesive, providing evidence for a crumbly texture. Using different experimental conditions than ours, Hwang & Gunasekaran (2001) and Sandra et al. (2004) determined Queso Fresco to be a crumbly cheese by TPA, finding consistency with sensory results. Springiness is a measure of the rebound of the specimen after the first compression, and ranged from 5.0 to 8.4 mm. In comparison, the Cheddar, Gouda, and Mozzarella have springiness values of 8.5 to 10.0 mm, meaning that Queso Fresco does not recover from compression very well. Chewiness is calculated by multiplying hardness, springiness, and cohesiveness, and the values of 10-24 mJ were much lower than those of other fresh cheeses (Tunick & Van Hekken, 2002). The cohesiveness, springiness, and chewiness values were within the ranges observed previously (Guo et al., 2011a).

None of the 10°C cheeses exhibited significant changes in the TPA values during storage, but the cheeses stored at 4°C lost some springiness and chewiness between 1 and 4 wk. The changes in the 4°C samples may have been due to loss of water during the test. The results were analogous to compressing a sponge. After 1 wk at 4°C, the first TPA compression squeezed a small amount of water from the specimen, which was able to recover somewhat for the second compression like a wrung-out sponge. More water was squeezed out of the other samples, and, like a saturated sponge, the specimens recovered less. The hardness was unaffected by water loss since it only measures the force required for the initial compression. Except for the springiness and chewiness values for the 4°C samples, the TPA data did not show significant differences from 1 to 8 wk despite the proteolysis that was observed. The β-casein levels decreased by half, but it is α_{s1}-casein that provides structural strength to the cheese matrix. The lesser degradation of α_{s1}-casein did not affect the hardness or cohesiveness to a significant extent.

3.5 Rheology

The torsion shear stress is a measure of the force required to twist a sample until fracture, the torsion shear strain indicates the angular deformation at fracture, and the torsion shear rigidity (shear stress divided by shear strain) is a measure of the sample brittleness. The values for shear stress for the Queso Fresco samples were between 9 and 13 kPa (Tables 4 and 5); the values for fresh Cheddar, Gouda, and Mozzarella are between 42 and 50 kPa (Tunick & Van Hekken, 2002), which shows that Queso Fresco fractures easily. The shear strain values of 0.69 and 0.87 were similar to that of fresh Cheddar (0.83), but much lower than Gouda (1.13) and Mozzarella (1.56). The shear rigidity values were between 11.2 and 17.3 kPa, lower than those of Cheddar, Gouda, and Mozzarella (52, 44, and 31 kPa, respectively). Queso Fresco therefore does not undergo much deformation before breaking, and is rather brittle. These results are consistent with the crumbly characteristics of a typical Queso Fresco.

The shear strain for all samples increased from 1 to 8 wk, which may be a reflection of wheying off affecting the ability to twist the specimen. The 10°C samples had significantly higher shear stress and shear rigidity values at 4 wk than at 1 or 8 wk, which may have been due to a combination of wheying off and lack of sample homogeneity. The torsion values were all within the ranges found previously (Guo et al., 2011a).

In SAOSA, G′ is a measure of the energy stored and recovered per oscillation and G″ is a measure of the energy dissipated and lost as heat per oscillation. The G′ values for all of the cheeses were between 11.6 and 17.4 kPa, and G″ values were from 3.2 to 4.5 kPa (Tables 4 and 5); the ranges found in an earlier study were 14.5-19.0 kPa for G′ and 4.1-5.3 for G″ (Guo et al., 2011a). In comparison, the G′ and G″ values for fresh Mozzarella cheese were 36 and 14 kPa, respectively, and the values for Cheddar and Gouda were higher (Tunick & Van Hekken, 2002). Relatively low values for G′ and G″ indicate that bonds between particles are being made and broken during the observation time, either spontaneously or from applied forces (Tunick, 2010). The SAOSA data indicate that the structure of Queso Fresco is granular and crumbly. The SAOSA results did not vary with storage temperature or time.

3.6 Color and melt

None of the Phase I samples melted, which is expected of this style of cheese. The high pH levels ensured that colloidal $CaPO_4$ would remain in the casein matrix, preventing melting.

The color properties changed significantly upon heating (Table 6). The change in a* values upon heating from positive (magenta) to negative (green) resulted in large changes in hue, which is based on the ratio of b* to a*. The largest decrease in whiteness (L*) was measured in samples heated at 130°C for 30 min (baking conditions) and resulted in ΔE values 2.5 times higher than those for samples heated at 232°C for 5 min (broiling conditions). Chroma values averaged 8.9 before heating, 14.6 after heating at 130°C, and 14.1 after 232°C heating. The corresponding values found in a previous study were 7.7, 15.6, and 12.0, respectively (Guo et al., 2011a). The only significant ΔE increase during storage was for cheese heated at 130°C for 30 min, where the values increased to 29.37 at wk 8. All other values were stable over 8 wk of storage at 4°C ($P > 0.05$).

3.7 Microstructure

In the SEM images, the round dark areas correspond to fat globules and the light areas correspond to the casein matrix (Figure 1). All specimens exhibited the same patterns of fat globules 0.5-2.0 μm in diameter, surrounded by a granular and rough-surfaced matrix. The microstructure was similar to that seen in an earlier study (Tunick & Van Hekken, 2010). The fused matrix commonly found in semi-hard and hard cheeses that have pH levels from 5.0 to 5.6 was not observed. The microstructure of the Queso Fresco did not change appreciably with storage at 4 or 10°C. If the protein matrix had degraded with time, which occurs with ripened cheeses, the images at 8 wk would have revealed a more open structure and possibly aggregation of fat globules. No microorganisms were observed in any of the images. The SEM results were indicative of cheeses that were not very cohesive and did not show structural damage during storage, which was consistent with the rheological results.

3.8 Sensory analysis

A total of 65 participants (33 males, 32 females) evaluated the Phase II cheeses. Six were 30 yr old and under, 19 were 31-50, and 40 were at least 50 yr old. All panelists reported they consume cheese; 51 eat cheese multiple times a week and 35 consume Hispanic cheese at least once a month. Based on the hedonic scale results, all three cheeses were generally liked (Figure 2). The laboratory samples had the highest number of “like extremely” but also had the highest number of "dislike slightly;" the overall average was "like slightly." The two commercial cheeses were in the "like moderately" category with C-1 having the highest number of "like very much."

In triangle tests, panelists could correctly distinguish laboratory from C-1 cheeses ($P < 0.001$) but could not separate laboratory and C-2 cheeses ($P > 0.1$). In ranking, C-2 was the first choice (average 1.74 of 3) whereas C-1 and laboratory were at 2.11 and 2.14, respectively. This result is interesting since C-2 had the highest score for liking and in ranking but could not be separated from laboratory cheese in side-by-side comparisons. The most common comment on ranking cheeses differently was perceived salt content. The laboratory cheeses, at 2.5% NaCl, were saltier than the commercial Queso Fresco at 1.8% NaCl.

4. Conclusions

Queso Fresco manufactured with pasteurized milk and without starter culture was analyzed throughout 8 wk of storage at 4 and 10°C. The cheese was crumbly and did not melt, and cheeses made in the laboratory could not be distinguished from a commercial sample by a consumer panel. Proteolysis and lipolysis occurred during storage, as evidenced in changes in lactose, pH, protein profiles, and volatile compounds, but had little or no effect on texture, rheology, melting, or microstructure. Cheesemakers and consumers can therefore store Queso Fresco for at least 2 mo without significant degradation of quality.

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Table 1. Composition of Phase I Queso Fresco cheeses during storage at 4°C (means from five production runs ± standard deviation)

	Storage time (wk)		
	1	4	8
Moisture (%)	$56.4^{a} \pm 0.9$	$56.0^{a} \pm 1.1$	$55.0^{a} \pm 1.0$
Fat (%)	$21.9^{a} \pm 1.4$	$21.2^{a} \pm 1.1$	$22.0^{a} \pm 1.2$
Protein (%)	$17.8^{a} \pm 1.0$	$18.0^{a} \pm 0.7$	$18.0^{a} \pm 0.9$
NaCl (%)	$1.79^{a} \pm 0.29$	$1.70^{a} \pm 0.20$	$1.51^{a} \pm 0.06$
Lactose (%)	$3.12^{a} \pm 0.40$	$3.31^{a} \pm 0.17$	$3.01^{a} \pm 0.18$
pH	$6.39^{a} \pm 0.10$	$6.27^{ab} \pm 0.09$	$6.22^{b} \pm 0.04$

[ab]Values with different superscript letters within the same row are different ($P < 0.05$).

Table 2. Composition of Phase II Queso Fresco cheeses during storage at 4 and 10°C (means from three production runs ± standard deviation)

	Storage time (wk)		
	1	4	8
Moisture (%)			
4°C	$56.2^{ab} \pm 1.7$	$55.9^{ab} \pm 2.9$	$56.7^{ab} \pm 2.3$
10°C	$56.9^{a} \pm 1.5$	$55.2^{ab} \pm 1.9$	$54.9^{b} \pm 1.9$
Fat (%)			
4°C	$21.8^{a} \pm 0.9$	$21.0^{a} \pm 0.9$	$21.5^{a} \pm 1.0$
10°C	$22.1^{a} \pm 0.5$	$21.6^{a} \pm 1.7$	$22.1^{a} \pm 1.3$
Protein (%)			
4°C	$15.2^{ab} \pm 1.0$	$15.7^{a} \pm 1.5$	$15.1^{ab} \pm 1.1$
10°C	$14.7^{b} \pm 0.8$	$15.3^{ab} \pm 1.6$	$15.0^{ab} \pm 0.5$
NaCl (%)			
4°C	$2.48^{a} \pm 0.04$	$2.30^{ab} \pm 0.32$	$2.13^{b} \pm 0.29$
10°C	$2.48^{a} \pm 0.04$	$2.30^{ab} \pm 0.30$	$2.12^{b} \pm 0.30$
Ash (%)			
4°C	$3.15^{a} \pm 0.35$	$3.39^{a} \pm 0.13$	$3.30^{a} \pm 0.43$
10°C	$3.21^{a} \pm 0.42$	$3.26^{a} \pm 0.30$	$3.26^{a} \pm 0.39$
Lactose (%)			
4°C	$2.71^{a} \pm 0.17$	$2.58^{a} \pm 0.20$	$2.68^{a} \pm 0.15$
10°C	$2.73^{a} \pm 0.26$	$2.50^{ab} \pm 0.25$	$2.45^{b} \pm 0.38$
Titratable acidity			
4°C	$0.15^{a} \pm 0.02$	$0.17^{a} \pm 0.03$	$0.20^{ab} \pm 0.03$
10°C	$0.14^{a} \pm 0.01$	$0.18^{a} \pm 0.04$	$0.33^{b} \pm 0.17$
pH			
4°C	$6.34^{a} \pm 0.07$	$6.38^{a} \pm 0.16$	$6.32^{a} \pm 0.18$
10°C	$6.32^{a} \pm 0.10$	$6.28^{a} \pm 0.18$	$6.10^{b} \pm 0.30$

^{ab}Values with different superscript letters within the same group are different ($P < 0.05$).

Table 3. Percentages of caseins and casein fragments in Phase II Queso Fresco cheeses during storage at 4 and 10°C (means from three production runs ± standard deviation)

		Storage time (wk)		
		1	4	8
Caseins		4°C storage		
α_{s2}		7.46 ± 3.05	6.39 ± 1.85	6.15 ± 1.85
α_{s1}		37.98 ± 6.45	33.67 ± 7.37	29.40 ± 7.11
β		32.35 ± 3.69	25.27 ± 3.35	19.39 ± 2.11
para-κ		10.35 ± 0.68	11.36 ± 0.98	11.44 ± 1.42
Fragments (kDa)				
22		0	6.67 ± 2.62	8.32 ± 2.48
22-18.5		4.10 ± 2.88	7.85 ± 3.31	11.55 ± 1.97
18-15		3.02 ± 2.22	3.24 ± 2.83	4.86 ± 2.85
< 14		2.64 ± 1.32	4.79 ± 1.87	7.63 ± 2.44
		10°C storage		
Caseins				
α_{s2}		7.00 ± 2.08	6.78 ± 1.49	6.06 ± 1.40
α_{s1}		36.09 ± 1.73	28.17 ± 4.14	23.05 ± 7.89
β		30.99 ± 0.55	19.08 ± 6.85	15.79 ± 1.58
para-κ		11.17 ± 0.83	12.71 ± 2.19	12.62 ± 1.37
Fragments (kDa)				
22		0	8.41 ± 3.22	12.00 ± 5.49
22-18.5		5.45 ± 1.86	9.82 ± 1.69	12.82 ± 2.06
18-15		3.51 ± 0.86	4.32 ± 2.80	4.74 ± 2.71
< 14		3.76 ± 0.67	9.40 ± 4.28	11.64 ± 2.20

Table 4. Texture profile analysis and rheology of Phase I Queso Fresco cheeses during storage at 4°C (means from five production runs ± standard deviation)

	Storage time (wk)		
	1	4	8
Hardness (N)	14.1^{a} ± 3.0	14.4^{a} ± 3.3	13.0^{a} ± 2.6
Springiness (mm)	7.97^{a} ± 1.21	6.73^{b} ± 1.43	6.81^{b} ± 1.33
Cohesiveness	0.20^{a} ± 0.04	0.19^{a} ± 0.03	0.20^{a} ± 0.05
Chewiness (mJ)	22.8^{a} ± 7.8	18.0^{a} ± 5.7	18.3^{a} ± 7.8
Shear stress (kPa)	10.42^{a} ± 4.25	10.91^{a} ± 2.77	9.62^{a} ± 2.08
Shear strain	0.69^{a} ± 0.06	0.82^{b} ± 0.08	0.84^{b} ± 0.10
Shear rigidity (kPa)	15.21^{a} ± 6.57	13.47^{a} ± 4.20	11.65^{a} ± 2.88
Elastic modulus (kPa)	17.39^{a} ± 6.32	16.80^{a} ± 5.48	16.78^{a} ± 5.79
Viscous modulus (kPa)	4.51^{a} ± 1.60	4.42^{a} ± 4.73	4.50^{a} ± 1.24

^{ab}Values with different superscript letters within the same row are different ($P < 0.05$).

Table 5. Texture profile analysis and rheology of Phase II Queso Fresco cheeses during storage at 4 and 10°C (means from three production runs ± standard deviation)

	Storage time (wk)		
	1	4	8
Hardness (N)			
4°C	13.3^{a} ± 3.0	12.5^{a} ± 4.0	14.1^{a} ± 3.5
10°C	12.2^{a} ± 2.7	13.0^{a} ± 4.4	13.1^{a} ± 2.1
Springiness (mm)			
4°C	8.35^{a} ± 0.49	5.06^{b} ± 0.35	5.61^{b} ± 0.54
10°C	6.41^{b} ± 1.54	5.94^{b} ± 1.21	6.19^{b} ± 1.78
Cohesiveness			
4°C	0.17^{a} ± 0.04	0.15^{a} ± 0.04	0.13^{a} ± 0.06
10°C	0.19^{a} ± 0.04	0.18^{a} ± 0.04	0.17^{a} ± 0.09
Chewiness (mJ)			
4°C	23.8^{a} ± 4.0	10.1^{b} ± 2.9	11.1^{b} ± 5.6
10°C	15.3^{b} ± 7.1	14.1^{b} ± 7.3	13.9^{b} ± 8.3
Shear stress (kPa)			
4°C	10.0^{ab} ± 1.8	11.7^{ac} ± 2.6	10.9^{ab} ± 1.9
10°C	9.4^{b} ± 2.1	13.0^{c} ± 3.9	9.4^{b} ± 3.0
Shear strain			
4°C	0.71^{a} ± 0.09	0.81^{ab} ± 0.08	0.83^{b} ± 0.12
10°C	0.76^{ab} ± 0.09	0.76^{ab} ± 0.05	0.87^{b} ± 0.22
Shear rigidity (kPa)			
4°C	14.5^{ab} ± 3.9	14.9^{ab} ± 4.2	13.7^{bc} ± 4.4
10°C	12.9^{bc} ± 4.1	17.3^{a} ± 5.8	11.2^{c} ± 4.0
Elastic modulus (kPa)			
4°C	11.66^{a} ± 6.13	11.59^{a} ± 4.58	13.58^{a} ± 6.66
10°C	13.09^{a} ± 6.60	16.27^{a} ± 8.78	15.42^{a} ± 6.09
Viscous modulus (kPa)			
4°C	3.19^{a} ± 1.65	3.27^{ab} ± 1.40	3.89^{ab} ± 2.00
10°C	3.50^{ab} ± 1.80	4.40^{b} ± 2.29	4.28^{ab} ± 1.70

^{abc}Values with different superscript letters within the same group are different ($P < 0.05$).

Table 6. Color properties of Phase I Queso Fresco cheeses after 1 wk storage at 4°C (means from five production runs ± standard deviation)

Color properties[1]	Before heating		After heating	
			130°C for 30 min	232°C for 5 min
ΔE			$26.89^{a} \pm 4.56$	$9.96^{b} \pm 2.29$
Hue	$86.12^{a} \pm 1.21$		$-82.31^{b} \pm 3.93$	$-86.02^{b} \pm 3.25$
Chroma	$8.88^{b} \pm 0.63$		$14.57^{a} \pm 1.96$	$14.08^{a} \pm 1.34$
L*	$92.48^{a} \pm 0.93$		$67.53^{c} \pm 5.88$	$84.04^{b} \pm 3.77$
a*	$0.607^{a} \pm 0.203$		$-1.81^{b} \pm 0.66$	$-1.01^{b} \pm 0.82$
b*	$8.87^{b} \pm 0.633$		$14.29^{a} \pm 1.95$	$14.09^{a} \pm 1.32$

[1]ΔE = total color change, hue = hue angle, chroma = color saturation, L* = whiteness, a* = magenta/green, b* = yellow/blue.

[abc]Values with different superscript letters within the same row are different ($P < 0.05$).

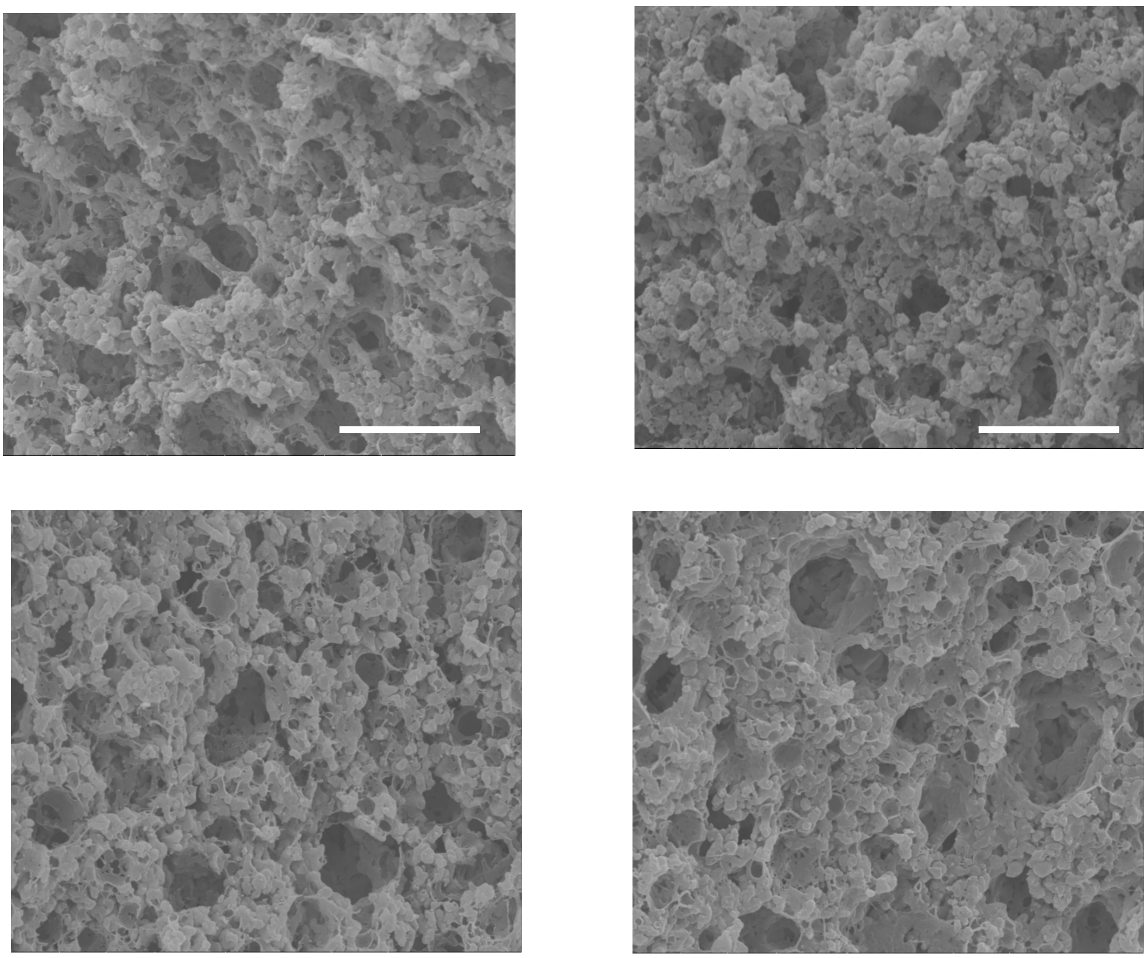

Figure 1. Scanning electron micrographs of Queso Fresco cheeses stored at 4 or 10°C for 1 or 8 wk

Upper left: 4°C, 1 wk. Upper right: 10°C, 1 wk. Lower left: 4°C, 8 wk. Lower right: 10°C, 8 wk. Bars at lower right of each micrograph measure 2.0 μm.

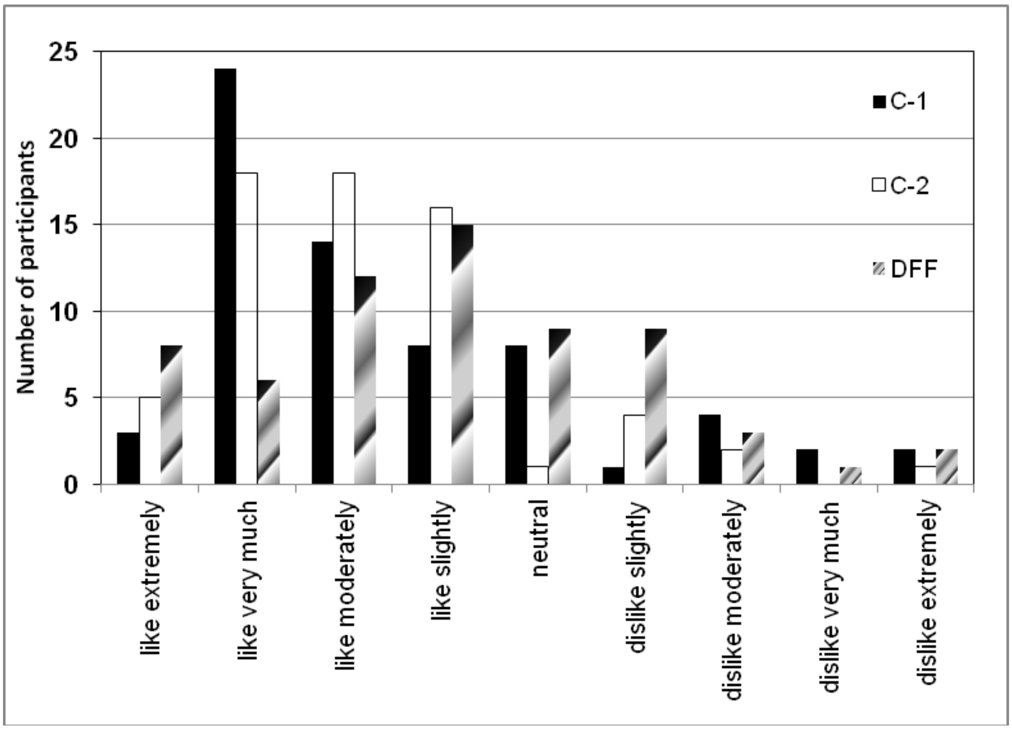

Figure 2. Hedonic scores for fresh Queso Fresco cheeses. C-1 and C-2 are two commercial samples and DFF was made in the Dairy & Functional Foods Research Unit laboratory