Behavior of stabilizers in acidified solutions and their effect on the textural, rheological, and sensory properties of cream cheese

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ABSTRACT

Stabilizers are routinely added during cream cheese manufacture to help prevent syneresis during storage. We investigated how different types of stabilizers affected the texture, rheology, and sensory properties of cream cheese. Cream cheeses were manufactured with 0.33% xanthan gum (XG), locust bean gum (LBG), guar gum (GG), or a combination (CBN) of these 3 stabilizers (0.11% of each). Rheological properties of solutions of the individual stabilizers and their combination (equal amounts) were also determined under conditions similar to the aqueous phase of cream cheese (0.6% gum, 1.8% NaCl, and pH 5). Dynamic small amplitude rheological properties of the cream cheeses were measured during heating from 5 to 80°C at the rate of 1°C/min and cooling at the same rate (because most cream cheese is hot packed/filled before cooling). Measured rheological parameters included storage modulus (G') and loss tangent. Hardness of cream cheeses was determined by texture profile analysis. Quantitative spectrum descriptive sensory analysis was also performed. Distinct differences were observed between the rheological properties of solutions of the individual stabilizers and the CBN containing all the stabilizers. Results showed that CBN solution formed a strong, thermally reversible gel due to synergistic interaction between stabilizers, whereas XG solution formed a weak gel that was not greatly affected by temperature. Solutions of LBG and GG behaved rheologically as entangled polymer solutions. In the high-temperature (>35°C) region, cream cheeses made with XG and CBN showed higher G' values compared with other cream cheeses. The G' values were higher for XG- and CBN-stabilized cream cheeses than LBG- and GG-stabilized cream cheeses at several temperature regions during the cooling cycle.

The CBN-stabilized cream cheeses had higher hardness values than the cream cheeses manufactured with the individual stabilizers. Differences were observed between the sensory attributes of cream cheeses stabilized with CBN and those made with individual stabilizers. At low temperatures, the higher hardness and G' values of CBN-stabilized cream cheeses could be due to synergistic interaction between XG and galactomannans. The higher elasticity of XG-stabilized cream cheeses at high temperatures could be due to its higher thermal stability. This study showed that the stabilizers added during manufacture of cream cheese affected its texture, rheological, and sensory properties.

Key words: texture, rheology, cream cheese, xanthan, galactomannan

INTRODUCTION

Cream cheese is widely used as an ingredient in products such as flavored spreads and cheesecakes. These applications require cream cheese with specific textural and rheological characteristics. However, information is lacking on how different factors influence these properties. In particular, little information is available about the addition of different types of stabilizers.

During cream cheese manufacture, syneresis is desired when part of the whey is removed to help concentrate the curd (Guinee et al., 1993). However, serum (whey) separation following packaging is considered a major defect and should be minimized (Fox et al., 2000). Fresh acid cheeses (such as cream cheese) have pH values (~4.6 to 5.0) that are near the isoelectric pH of caseins where the water-holding capacity of these proteins is reduced (Gigante et al., 2006). The primary role of stabilizers in cream cheese is to prevent syneresis during storage (Kosikowski and Mistry, 1997). Addition of stabilizers helps prevent syneresis primarily by increasing the viscosity of the aqueous phase (Bot and Vervoort, 2006). In cream cheese, stabilizers are added to the separated curd (i.e., after part of the whey is removed from the curd; Schulz-Collins and Senge, 2004). Addition of stabilizers before whey removal would

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probably interfere with the expulsion of moisture (i.e., make it harder to remove sufficient moisture during the mechanical separation step). In cream cheese, stabilizers are added to the hot stirred, acidified product that has a high viscosity. During the addition of stabilizers, the cream cheese curd is usually heated ($>70^{\circ}\text{C}$) and stirred to enhance the dispersion/hydration of these stabilizers in the aqueous phase of cream cheese. In addition, heating decreases viscosity, allowing the product to be pumped, mixed, and packaged (Lucey, 2002).

The most commonly added stabilizers in cream cheeses manufactured in the United States are xanthan gum (**XG**), locust bean gum (**LBG**), or guar gum (**GG**; Hunt and Maynes, 1997). Often, a combination (**CBN**) of these 3 gums is used to stabilize cream cheese, although they are also used individually. Xanthan gum is an anionic polysaccharide composed of a (1,4)- β -D-glucan backbone that is substituted at C-3 on alternate glucose residues by a trisaccharide side chain (Morris, 1995; Pelletier et al., 2001). This side chain consists of β -D-mannose-(1,4)- β -D-glucuronic acid-(1,2)- β -D-mannose with variable levels of noncarbohydrate constituents acetate and pyruvate located in the inner and terminal mannose residues, respectively (Pelletier et al., 2001). Locust bean gum and GG are galactomannans composed of a linear backbone of (1,4)- β -D-mannose residues substituted with (1,6)- α -D-galactose residues. Typical mannose/galactose ratios of LBG and GG are 3.55 and 1.56, respectively (Morris, 1998).

The rheological properties of solutions of these 3 stabilizers, and their mixtures, have been previously studied and results indicated that their rheological behavior greatly differ (Richardson and Ross-Murphy, 1987a,b; Copetti et al., 1997). Galactomannans give viscous solutions (Dea, 1990), whereas XG forms weak gels that, in the presence of salt, exhibit an increased stability to heat and acid conditions (Morris, 1990). Several studies have reported a synergistic interaction between XG and galactomannans (Williams and Phillips, 1995). Most studies indicate that the synergistic interaction between XG and galactomannans is due to direct interactions rather than to any thermodynamic incompatibility (Morris, 1995). However, no molecular model or mechanism is universally accepted for the interaction between XG and galactomannans. When LBG and XG are combined, strong, thermally reversible gels are formed, whereas mixtures of XG and GG give solutions of high viscosity (Morris, 1998). Little information is available on the properties of mixtures of all 3 (LBG, XG, and GG) of these polysaccharides, or when evaluated under the conditions present in cream cheese (high salt, low pH).

Stabilizers can greatly affect the rheology of food systems even when added in small concentrations.

According to Guinee et al. (1993), in fresh acid-curd cheeses, addition of hydrocolloids that bind to the protein network (e.g., κ -carrageenan, pectin) interrupt the formation of protein-protein interactions and give softer products. The stabilizers selected for this study, XG, LBG, and GG, do not directly bind (associate) to caseins (Everett and McLeod, 2005). Previous studies have indicated that the addition of nonadsorbing hydrocolloids to skim milk before acidification can introduce changes in the acid-induced gel microstructure (Sanchez et al., 2000; Aichinger et al., 2007) and in the rheology of acid-induced gels (Aichinger et al., 2007). In cream cheese, stabilizers are added to the fermented product.

The objective of this study was to determine how the stabilizers: XG, LBG, GG, and CBN affect the rheological, textural, functionality, and sensory properties of cream cheese. The rheological properties of solutions of these stabilizers and of their equal combination were also characterized and compared with the rheological behavior of cream cheeses stabilized with these hydrocolloids.

MATERIALS AND METHODS

Rheological Properties of Solutions of Stabilizers

The stabilizers used in this study were XG (Satiexane CX90 DF, Cargill Inc., Minneapolis, MN), LBG (Viscogum BE, Cargill Inc.), and GG (Viscogum 202, Cargill Inc.).

Rheological properties of the stabilizer solutions were determined by a controlled-stress rheometer Paar Physica UDS 200 (Physica Messtechnik, Stuttgart, Germany). A cup and bob measuring geometry (Z3 DIN) consisting of 2 coaxial cylinders with inner and outer diameters of 25.0 and 27.5 mm, respectively, was used. Solutions of XG, LBG, GG, and CBN were prepared under conditions similar to those of the aqueous phase of cream cheese (0.6% stabilizers, 1.8% NaCl, and pH 5.0). Stabilizers, together with the salt, were dissolved in deionized water at room temperature. Sodium azide (0.02%) was added to prevent bacterial growth and the pH was adjusted to 5.0 with lactic acid. Solutions were stored at 5°C until they were analyzed.

Solutions of stabilizers were first heated to 80°C for 30 min in a water bath while being vigorously stirred (for rehydration purposes). Solutions were transferred to the cup system of the rheometer while they were still hot, where they were immediately cooled to 5°C and maintained at that temperature for 2 h before analysis. Vegetable oil was added to the surface of the sample in the rheometer to prevent evaporation. Frequency sweep tests were performed on the model stabilizer solutions

at a temperature of 5°C to determine the effect of the time-scale of deformation on their rheological properties. This was also performed to understand the nature of the system, that is, was the solution a gel? A strain of 1% was applied at frequencies that ranged from 0.001 to 1 Hz.

The effect of temperature on the behavior of the model stabilizer solutions was evaluated by temperature sweep tests. This was done to understand how these stabilizers might behave during the hot filling and cooling operations of cream cheese manufacture. Solutions were heated from 5 to 80°C and subsequently cooled from 80 to 5°C at a heating rate of 1°C/min. A frequency of 0.1 Hz and a strain of 1% were used while the storage modulus (G') and loss tangent (LT) were measured.

Large deformation properties of the solutions were also determined by applying a single, constant shear rate (0.232 s^{-1}) up to a yield point, which was defined as the point when the shear stress values started to decrease (Lucey et al., 1997). Parameters measured were yield stress (σ_{yield}) and yield strain at yielding (γ_{yield}).

Textural Properties of Solutions of Stabilizers

Solutions of stabilizers were first heated to 80°C for 30 min in a water bath while being vigorously stirred. Solutions were transferred to 250-mL plastic beakers and placed in the refrigerator ($\sim 4^\circ\text{C}$) for 1 d before analysis.

A penetration test was performed using a TA.TXT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) equipped with a 5-kg cell and a temperature-controlled chamber (Temperature Applied Sciences Ltd., West Sussex, UK) maintained at 4°C. The penetration test was carried out on the samples when they were in the chamber. A cylindrical stainless steel probe with a diameter of 45 mm (TA-94) was introduced 30 mm into the gels at a speed of 1 mm/s. The parameter measured was hardness, which was defined as the maximum force during penetration.

Cream Cheese Manufacture

Two licensed Wisconsin cheese makers manufactured 3 replicate trials of cream cheeses at the University of Wisconsin–Madison Dairy Plant as described by Brighenti et al. (2018). On each cheesemaking day, 4 square-shaped, jacketed stainless-steel open cheese vats (Stoelting LV60, Kiel, WI), with a maximum capacity of 272 kg of milk, were used to manufacture the cream cheeses on 3 separate days over a period of 3 mo. Cream cheese mix was prepared by blending whole milk and cream to obtain a fat content of $11.7 \pm 0.7\%$.

The standardized cream cheese mix was pasteurized at 77°C for 19 s and then homogenized (Gaulin Type 800E, W. M. Sprinkman Corp., Franksville, WI) in 2 stages (17.5 and 5 MPa). Each vat was filled with 136 kg of the cream mix. The mix was added to 4 different cheese vats where it was inoculated with a mesophilic bulk culture (0.1%, wt/wt, Flav 1; Cargill Texturizing Solutions, Waukesha, WI) containing *Lactococcus lactis* ssp. *lactis*, *Lactococcus lactis* ssp. *cremoris*, *Lactococcus lactis* ssp. *diacetylactis*, and *Leuconostoc mesenteroides* ssp. *cremoris*. Each cheese vat was incubated at 23°C until the pH reached ~ 4.70 . Each cultured mix was then stirred and heated until a temperature of 80°C was reached (~ 35 min). The hot mixtures were then pumped individually to a cream cheese centrifugal separator (Sharples centrifuge, model DS-2, Penwalt Corporation/Sharples Stokes division, Warminster, PA) where part of their whey was removed from the acid curds. After separation, approximately 36 kg of cream cheese was obtained and the curd was pumped into a jacketed swept surface holding tank (model CBP 30, Scherping Systems, Winsted, MN). Curd was constantly agitated for ~ 30 min while the temperature was held at $\sim 76^\circ\text{C}$. Salt (1%, wt/wt) and stabilizers (0.33%, wt/wt) were added during this period. Each cream cheese was stabilized with a different stabilizer: XG, LBG, GG, or CBN of these 3 stabilizers (0.11%, wt/wt of each). The moisture content of each curd was checked by a rapid microwave test (CEM Smart System 5 Moisture/Solids Analyzer, CEM Corporation, Matthews, NC), and if necessary, moisture was adjusted to $\sim 55\%$ by the addition of separated acid whey. After ~ 30 min of mixing, each curd was pumped into a cream cheese homogenizer (Gaulin Type 100DJ F3 8SS, W. M. Sprinkman Corp., Franksville, WI) where it was homogenized at 1.7 MPa for both stages. The curds were then hot-packaged at a temperature of $\sim 75^\circ\text{C}$ into five 2.2-kg cylindrical plastic containers (diameter: 14 cm, height: 19 cm) for each treatment. Samples were placed in a refrigerated room for storage at $\sim 4^\circ\text{C}$.

Compositional Analyses

Cream cheese mixes were analyzed for TS (IDF, 2010), fat by Mojonnier (AOAC International, 2000), total protein (total percentage N $\times 6.35$) by Kjeldahl (AOAC International, 2000), true protein, casein (Marshall, 1992), and total Ca using inductively coupled plasma emission spectroscopy (Govindasamy-Lucey et al., 2007). Lactose was determined by an enzymatic method (AOAC International, 2000; Boehringer Mannheim Biochemicals, Mannheim, Germany).

Cream cheeses were analyzed 1 wk after manufacture for moisture (IDF, 2004), fat (AOAC International,

2000), total protein by Kjeldahl (AOAC International, 2000), salt (Corning Salt Analyzer, Corning Glass Works, Medfield, MA; Marshall, 1992), total Ca using inductively coupled plasma emission spectroscopy (Govindasamy-Lucey et al., 2007), and lactose and lactic acid (AOAC International, 2000; Boehringer Mannheim Biochemicals). The pH values were determined by insertion of a pH probe (pH meter 420A, Orion Research, Beverly, MA) into the cheeses.

Preparation of Cream Cheese Samples for Rheological and Textural Analyses

Samples for rheological tests, were prepared as described by Brighenti et al. (2018). Fifty-milliliter syringes (Henke-Sass Wolf GmbH, Tuttlingen, Germany) with an internal diameter of 29 mm were used, whereas for texture analysis, the syringes (Becton, Dickinson and Company, Franklin Lakes, NJ) had a volume of 20 mL and an internal diameter of 16 mm. The syringes had their nozzles removed (cut off) and these syringes were filled with cream cheese during the manufacturing process at the packaging stage (i.e., while it was still hot, and therefore liquid/viscous). Three syringes filled with cream cheese were stored inside the middle of the 2.2-kg plastic containers assigned for rheological analyses. Likewise, 3 syringes allocated for textural analyses were filled with cream cheeses and stored in separate containers assigned for textural analyses. The containers were filled with cream cheese and this allowed the syringes to cool along with the rest of the product in a cold room at 4°C. This was done to have a similar cooling profile as the rest of the cream cheese samples. The cream cheeses in these containers were not used for any other analyses. After 4 wk of storage at 4°C, the samples were extruded out of the syringes as a cylinder using the plunger of the syringe. Samples were cut to the desired thickness using a cheese slicer (samples were maintained at ~4°C). For rheological tests, samples had a thickness of 2 to 3 mm and a diameter of 29 mm, whereas samples for texture analysis had diameter and height of ~16 mm. Samples were stored at 4°C for at least 2 h to allow for structure recovery from the preparation steps before they were analyzed for their rheological or textural properties.

Rheological and Textural Properties of Cream Cheeses

The rheological properties of cream cheeses were determined by the dynamic small-amplitude oscillatory rheology technique as described by Brighenti et al. (2018). A controlled-stress rheometer (Paar Physica

UDS 200, Anton Paar, Ashland, VA) with a 25-mm serrated probe and a parallel plate geometry was used. A frequency of 0.1 Hz and a strain of 0.05% were used (strain sweep tests indicated that this was within the linear viscoelastic region; results not shown). Samples were heated from 5 to 80°C and immediately cooled from 80 to 5°C at a heating rate of 1°C/min. Samples were maintained at 5°C for 30 min. All analyses were carried out in triplicate. The parameters measured were G' and LT .

Textural Properties of Cream Cheeses

Texture profile analysis was performed using the TA.XT2 Texture Analyzer equipped with the 5-kg cell and the temperature-controlled chamber maintained at 4°C. Analyses were carried out at 4°C by placing the samples in the chamber. Cylindrical samples were compressed twice with a 50-mm aluminum cylindrical probe at a speed of 1 mm/s and compressed to a strain of 60%. All tests were replicated at least 5 times. The parameter measured was hardness, which was defined as the maximum force during the first compression.

Sensory Textural Properties of Cream Cheeses

A trained sensory panel consisting of at least 8 panelists (usually 8 to 12) used quantitative spectrum descriptive analysis (Meilgaard et al., 1999) to evaluate the following textural attributes of cream cheese: firmness, stickiness, cohesiveness of mass, gumminess, difficulty to dissolve, particle size, and difficulty to spread. The training of the panel, the choice of the textural attributes and the references used to quantify their intensity as well as the preparation of samples and their evaluation were previously described (Brighenti et al., 2008, 2018). All sensory panels were conducted in duplicate on 2 different days.

Experimental Design and Statistical Analysis

Three replicate cheesemaking trials were carried out; in each trial, 4 cream cheeses were manufactured. Each cream cheese was stabilized with a different stabilizer: XG, LBG, GG, or CBN of these 3 stabilizers (0.11%, wt/wt of each). The effects of type of stabilizer on the rheological, textural, and sensory properties of cream cheeses were determined by using PROC Mixed for repeated measurement in SAS software (version 8.02, SAS Institute Inc., Cary, NC). When treatment effect was significant ($P \leq 0.05$), the difference between means was analyzed using Duncan's method for multiple comparisons of means.

Figure 1. Storage modulus (G') values (●) and loss modulus (G'') values (○) of solutions containing 0.6% stabilizers, 1.8% NaCl, and pH 5.0 for xanthan gum (a), locust bean gum (b), guar gum (c), or a combination of all 3 stabilizers (0.2% each of xanthan, locust bean gum, and guar gum; d) as a function of frequency. Samples were tested at 5°C. Values are means of 3 replicates and error bars represent SD of the mean.

RESULTS AND DISCUSSION

Rheological Properties of Solutions of Stabilizers

Clear differences were observed in the frequency sweep profiles for the various stabilizer solutions at the concentration, salt level, and pH values selected for this study (Figure 1). Solutions of XG (Figure 1a) and CBN (Figure 1d) had higher values of G' than G'' at all frequencies compared with solutions of LBG (Figure 1b) or GG (Figure 1c). The CBN solution had higher G' values (Figure 1d) and greater frequency-independence than those of the XG solution (Figure 1a). In the case of the solutions of galactomannans, values of G' were lower than those of G'' until crossover frequencies were exceeded ($G' = G''$ at ~4 Hz for LBG and at ~1 Hz for GG; Figures 1b and 1c, respectively). At frequencies

higher than the crossover frequencies, G' values were higher than those of G'' for solutions of LBG and GG. These profiles indicated that solutions XG and CBN formed gels, whereas LBG and GG were entangled solutions (not gels; Pai and Khan, 2002).

During the heating cycles in temperature sweep experiments, the CBN solutions had the highest G' values at temperatures below ~35°C (Figure 2a). During heating, the G' values of CBN solutions decreased up to 60°C; thereafter the G' values hardly changed (Figure 2a). Storage modulus values of XG solutions also decreased slightly with increasing temperature. Storage modulus values of GG and LBG were $\ll 1$ Pa at all temperatures during the heating and cooling cycles (Figure 2). During the cooling cycle (Figure 2b), the G' values of CBN and XG increased as the temperature decreased. The G' values of CBN and XG solutions after the heating

Figure 2. Storage modulus values of solutions of 0.6% stabilizers, 1.8% NaCl, and pH 5.0 for xanthan gum ($\circ$), locust bean gum ($\square$), guar gum ($\blacktriangledown$), and a combination of all 3 stabilizers (xanthan, locust bean gum, and guar gum; $\blacklozenge$) during heating (a) and cooling (b). Heating was from 5 to 80°C and cooling from 80 to 5°C at 1°C/min. Values are means of 3 replicates and error bars represent SD of the mean.

and cooling cycles were similar to those obtained before heating. The LT values of the CBN and XG solutions were <0.4 at all temperatures studied during the heating and cooling cycles (Figures 3a and b). During the heating cycle, the CBN solution showed a maximum value (~ 0.28) at approximately 56°C, and during the cooling cycle, a maximum (~ 0.24) was observed at approximately 50°C. The LT values of XG solution were higher than those observed in the CBN solution at all temperatures; however, XG solution showed no clear LT peak in this temperature range. For LBG and GG solutions, G'' values were higher than G' values at all temperatures and therefore their LT values were >1 .

The CBN solution formed gels with highest σ_{yield} and γ_{yield} values (Table 1). Gels with lower σ_{yield} and γ_{yield} values were obtained for XG, whereas solutions of LBG

and GG did not exhibit a detectable yield point under the conditions of this experiment. In addition, the gels formed by CBN solutions had the highest hardness, with values ~ 19.6 N, whereas the weaker gels formed in XG solutions had hardness values ~ 0.98 N and solutions of GG and LBG had values ~ 0.49 N (results not shown).

In the case of XG solutions, results from the frequency sweep test (i.e., $G' > G''$ at all frequencies; Figure 1a) and the presence of a yield stress (Table 1) are both indicators of the presence of a gel. The behavior of XG during the heating and cooling cycles of the temperature sweep test indicated that the structure present in this solution was relatively stable over the temperature range from 5 to 80°C. The decrease in the G' values with an increase in temperature was not very pro-

Figure 3. Loss tangent values of solutions of 0.6% stabilizers, 1.8% NaCl, and pH 5.0 for xanthan gum ($\circ$), locust bean gum ($\square$), guar gum ($\blacktriangledown$), and a combination of all 3 stabilizers (xanthan, locust bean gum, and guar gum; $\blacklozenge$) during heating (a) and cooling (b). Heating was from 5 to 80°C and cooling from 80 to 5°C at 1°C/min. Values are means of 3 replicates and error bars represent SD of the mean.

Table 1. Large deformation properties¹ of the different stabilizer solutions

Gum solution	Yield stress ² (Pa)	Yield strain ²
Combination	188.5 ± 17.7	1.4 ± 0.1
Xanthan	9.6 ± 0.7	0.9 ± 0.0
Guar	NY ³	NY
Locust bean	NY	NY

¹Mean and SD of triplicate experiments.

²Yield was defined as the point when the shear stress started to decrease when gels were subjected to a constant shear rate of $\sim 0.232 \text{ s}^{-1}$.

³NY = no yield point observed under the conditions of the experiment.

nounced (Figure 2a), and little change was observed in the LT values as they remained <1 at all temperatures, indicating the presence of a solid-like gel structure in the material (Figures 3a and b). The behavior of XG in solution has been frequently described as resembling that of a weak gel (Morris, 1998). According to Rochefort and Middleman (1987) at the concentration used in this study (0.6%), the rheological behavior of XG is mainly determined by intermolecular interactions. At low temperatures and low ionic strength, XG molecules are in a partially ordered form that is extended due to electrostatic repulsion from the side chains (Rochefort and Middleman, 1987). These highly extended molecules associate through non-covalent interactions to form weakly structured materials (Khouryieh et al., 2007). When heated above 40°C , the partially ordered molecules become coil-like structures; molecules are then dissociated and the structure of the solution is disrupted (Rochefort and Middleman, 1987). However, when the ionic strength of the solution is increased, the charges from the side chains of XG are screened and these side chains fold onto the backbone, forming a helical configuration (Muller et al., 1986). An increase in the ionic strength of a XG solution results in an increase in structure (higher G' and G'' values) as the ordered molecules of XG align and associate more easily through non-covalent interactions. Also, at high ionic strengths, the transition from the ordered configuration to the coil-like structure occurs at higher temperatures (Kitamura et al., 1990). In the XG solution prepared for our study, the ionic strength was high ($\sim 1.6\%$ NaCl) to mimic the aqueous phase of cream cheese, which could explain the high thermal stability of the structure present in the XG solution.

In the case of the galactomannans, LBG and GG, the values of G' and G'' obtained from the frequency sweep tests (Figures 1b and c) indicated that they behaved as weakly viscous or entangled solutions (Daubert and Foegeding, 1998). Robinson et al. (1982) and Sittikijyothin et al. (2005) found that at room temperature and at concentrations similar to those used in this study, solutions of GG and LBG behaved as weakly viscous

solutions (i.e., G'' values were higher than G' at all frequencies). Crossover frequencies were only present at higher concentrations ($\sim 3\%$) for these galactomannans (Robinson et al., 1982; Sittikijyothin et al., 2005). A crossover was observed in our study and this difference could be due to the lower temperature used in our study (5°C), which favors the formation of some non-covalent interactions (i.e., hydrogen bonds) between molecules. The large deformation tests for GG and LBG solutions indicated that no yield point was observed (Table 1), under the conditions selected for this experiment, which is in agreement with the suggestion of an entangled polymer solution (Figure 1). The low G' values and LT values >1 at all temperatures during the heating and cooling cycles also indicate the presence of viscous solutions (not gels) under these conditions (Figures 2 and 3).

For the CBN solution, the characteristic pattern obtained from the frequency sweep test ($G' > G''$ at all frequencies; Figure 1d) and the presence of a yield stress when subjected to the large deformation test (Table 1), indicated the presence of a gel network. The gel formed in the CBN solution was stiffer than those formed by XG, as evidenced by the higher values for G' and G'' , the higher frequency independence obtained from the frequency sweep test (Figure 1d), the higher values of σ_{yield} and γ_{yield} obtained from the large deformation test (Table 1), and the higher hardness obtained from the penetration test (results not shown). From the temperature sweep tests, the CBN gel showed the highest G' values at low temperatures ($<25^\circ\text{C}$); these values decreased steeply up to $\sim 60^\circ\text{C}$ during the heating phase from 5 to 80°C (Figure 2a). During cooling, the increase in G' values with a decrease in temperature, and the recovery of the structure after the heating and cooling cycles, indicated that the CBN gel was thermally reversible. The maxima in the LT values during heating occurred at $\sim 56^\circ\text{C}$ and cooling at $\sim 50^\circ\text{C}$ indicated that transitions in the structure of the gel occurred at these temperatures. However, the LT values of the CBN did not exceed 1.0 at any temperature during the heating or cooling cycle (Figures 3a and b), which indicated the presence of a more solid-like than liquid-like structure even after the gel was weakened by heating.

At 5°C , the CBN system formed a gel with a stiffer structure compared with those of the individual stabilizer solutions. This indicates a synergistic interaction between XG and galactomannans, which has been previously reported by many authors (e.g., Williams and Phillips, 1995). Xanthan forms thermally reversible gels with LBG; in mixtures with GG, viscosity is increased (Morris, 1998). Although the structure of the CBN gel greatly weakened at temperatures $>60^\circ\text{C}$, some structure was still present as evidenced by the LT values

<1. Previous studies (Fernandes, 1995) also observed values of LT <1 in gels formed between LBG and XG when heated up to 70°C, which they attributed to the individual contributions of XG and LBG molecules to the structure of the system.

Compositional Analyses of Cream Cheese Mixes and Cream Cheeses

The average composition of the standardized cream mixes used to manufacture the cream cheeses are $19.6 \pm 0.7\%$ TS, $11.7 \pm 0.7\%$ fat, $2.7 \pm 0.1\%$ true protein, $2.4 \pm 0.1\%$ casein, and $4.1 \pm 0.1\%$ lactose. The total calcium contents of the cream mixes were 102 ± 6 mg/100 g of milk. Cream cheeses with similar chemical compositions were produced to avoid possible changes in texture and rheology due to any variation in composition (Table 2). No significant differences were observed between the concentrations of moisture, fat, protein, lactose, and lactic acid in the cream cheeses stabilized with the different stabilizers. The target composition of cream cheeses were close to the maximum moisture content of 55% and a minimum fat content of 33%, according to the US standard of identity of cream cheese (Code of Federal Regulations, 2006).

Rheological Properties of Cream Cheese

The G' values of the cream cheeses stabilized with XG, LBG, GG, and CBN were not significantly different at low temperatures (<30°C) during the heating cycle of the temperature sweep tests (Figure 4a). At low temperatures, the protein matrix, and the mostly solid fat embedded in the matrix, were probably the dominant contributors to the G' values of cream cheeses. During heating at higher temperatures (from 30 to 70°C), XG-

and CBN-stabilized cream cheeses exhibited higher G' values than the cream cheeses stabilized with the galactomannans (LBG and GG). No significant differences were observed between the LBG- and GG-stabilized cream cheeses, or between those stabilized with the CBN and XG at any temperature during the heating cycle. The higher G' values of XG and CBN-stabilized cream cheeses could be because both stabilizer systems (XG and CBN) form gels in the aqueous phase of cream cheeses as observed in our model solutions. The presence of CBN gels in the aqueous phase of cream cheeses may reduce the mobility of the system, increase its structural stability to high temperatures and contribute to its overall stiffness.

During the cooling cycle, XG-stabilized cream cheeses tended to have higher G' values than the cream cheeses stabilized with the galactomannans (LBG and GG; Figure 4b). The CBN-stabilized cream cheeses had significantly higher G' values than those stabilized with GG and LBG at temperatures below 65°C and had the significantly ($P < 0.05$) highest G' values at temperatures below 8°C. When comparing the cream cheeses stabilized with GG to those stabilized with LBG, no significant differences ($P > 0.05$) were observed at any temperature during the heating or cooling cycles.

All samples exhibited a LT peak at temperatures between 20 to 30°C during the heating cycle (Figure 5a). A weak second LT peak was observed at ~60°C in some samples during the heating cycle (Figure 5a). Similar LT profiles were reported in full-fat commercial cream cheese by Brighenti et al. (2008). The CBN-stabilized cream cheese had lower LT values from 35 to 65°C than in the GG and LBG-stabilized cream cheeses (Figure 5a). No significant differences were observed between CBN and XG-stabilized cream cheeses. During the cooling cycle, at temperatures that ranged from 50

Table 2. Composition¹ of cream cheeses made with individual stabilizers (0.33%) or a combination of all 3 stabilizers (total of 0.33%; n = 3)

Item	Treatment ²			
	Xanthan	Locust bean	Guar	Combination
Moisture (%)	55.41 ^a	55.61 ^a	55.98 ^a	54.99 ^a
Fat (%)	33.06 ^a	32.74 ^a	33.26 ^a	33.33 ^a
Salt (%)	0.90 ^a	0.82 ^b	0.87 ^{ab}	0.83 ^{ab}
Protein (%)	7.30 ^a	7.19 ^a	7.13 ^a	7.23 ^a
Lactose (%)	2.41 ^a	2.33 ^a	2.40 ^a	2.33 ^a
Lactic acid (%)	0.35 ^a	0.34 ^a	0.34 ^a	0.31 ^a
pH	4.93 ^b	5.02 ^a	5.02 ^a	5.05 ^a

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Mean of triplicate experiments.

²Xanthan = cream cheese manufactured with 0.33% xanthan gum as a stabilizer; locust bean = cream cheese manufactured with 0.33% locust bean gum as a stabilizer; guar = cream cheese manufactured with 0.33% guar gum as a stabilizer; and combination = cream cheese manufactured with a combination (total = 0.33%) of 0.11% xanthan gum, 0.11% locust bean, and 0.11% guar gum as a stabilizer.

Figure 4. Storage modulus values of cream cheeses made with xanthan gum (○), locust bean gum (□), guar gum (▼), and a combination of all 3 stabilizers (xanthan, locust bean gum, and guar gum; ◆) during heating (a) and cooling (b). Heating was from 5 to 80°C and cooling from 80 to 5°C at 1°C/min. Total concentration of stabilizer (0.33%) was the same in all cream cheeses; the combination contained 0.11% of each stabilizer. Values are means of 3 replicates and error bars represent SD of the mean.

to 15°C, the LT values of the CBN-stabilized cream cheeses were lower than those of the cream cheeses made with the individual stabilizers. The LT values of CBN-stabilized cream cheeses at different temperature regions of the heating and cooling cycles were significantly lower than the LT values of the cream cheeses made with the individual stabilizers (Figures 5a and b). This is in agreement with the LT values obtained for the CBN solutions, which were significantly ($P < 0.05$) lower than the values obtained for the individual solutions of XG, LBG, and GG at all temperatures of the heating and cooling cycles (Figures 3a and b). However, the magnitude of the differences between the LT values of the various types of cream cheeses was small. In all cases, LT values were relatively low (i.e., <0.40), which indicate that throughout the heating cycle, cream

cheese structure remained solid-like. Low LT values of cream cheese during heating are characteristic for this type of cheese (Brighenti et al., 2008, 2018), and are likely due to its low pH (Johnson and Lucey, 2006). No significant ($P > 0.05$) differences were observed in the LT values between cream cheeses stabilized with the individual stabilizers (XG-, GG-, or LBG-stabilized cream cheeses) at any temperature during the heating or cooling cycles.

Instrumental Texture and Sensory Properties of Cream Cheeses

The textural results from both instrumental and sensory analyses indicate that the cream cheeses stabilized with the individual stabilizers were not sig-

Figure 5. Loss tangent values of cream cheeses made with xanthan gum (○), locust bean gum (□), guar gum (▼), and a combination of all 3 stabilizers (xanthan, locust bean gum, and guar gum; ◆) during heating (a) and cooling (b). Heating was from 5 to 80°C and cooling from 80 to 5°C at 1°C/min. Values are means of 3 replicates and error bars represent SD of the mean. Total concentration of stabilizer (0.33%) was the same in all cream cheeses; the combination contained 0.11% of each stabilizer.

Table 3. Instrumental textural (determined by texture profile analysis; TPA) and sensory properties¹ of cream cheeses manufactured with different stabilizers as evaluated by trained sensory panelists after storage for 1 mo at 4°C (n = 3)

Item	Treatment ²			
	Xanthan	Locust bean	Guar	Combination
TPA hardness ³ (N)	7.4 ^a	8.7 ^a	7.7 ^a	11.3 ^b
Sensory attribute ⁴				
Firmness	10.2 ^b	10.9 ^b	10.7 ^b	12.0 ^a
Stickiness	6.7 ^a	6.6 ^a	7.1 ^a	5.0 ^b
Gumminess	6.5 ^b	6.6 ^b	6.3 ^b	7.3 ^a
Cohesiveness of mass	11.0 ^b	11.2 ^b	11.3 ^b	12.7 ^a
Difficulty to dissolve	10.6 ^b	10.7 ^b	10.7 ^b	11.6 ^a
Difficulty to spread	8.9 ^b	9.4 ^b	9.4 ^b	10.6 ^a

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Mean of triplicate experiments.

²Xanthan = cream cheese manufactured with 0.33% xanthan gum as a stabilizer; locust bean = cream cheese manufactured with 0.33% locust bean gum as a stabilizer; guar = cream cheese manufactured with 0.33% guar gum as a stabilizer; and combination = cream cheese manufactured with a combination (total = 0.33%) of 0.11% xanthan gum, 0.11% locust bean, and 0.11% guar gum as a stabilizer.

³Hardness was measured by texture analyzer.

⁴The numerical intensity scale for each attribute ranged from 0 to 15; higher numbers indicate higher intensities.

nificantly ($P > 0.05$) different from each other (Table 3). However, the CBN-stabilized cream cheeses had a firmer texture than the cream cheeses made with the individual stabilizers as evidenced by higher values of hardness determined by texture profile analysis, and sensory attributes such as firmness, cohesiveness of mass, difficulty to dissolve, gumminess, and difficulty to spread (Table 3). At low temperatures ($<40^{\circ}\text{C}$) the small deformation properties did not significantly differ between all samples (Figure 4), in contrast to the textural differences observed between cheeses stabilized by CBN and the other stabilizers (Table 3). Texture and sensory analysis are large deformation tests where yielding/fracture behavior are involved, which are in contrast to nondestructive rheological methods. In a previous study (Brighenti et al., 2008), we found that in cream cheese, the sensory parameters firmness, cohesiveness of mass, difficulty to dissolve, gumminess, and difficulty to spread were strongly correlated and associated with the hardness of the product. No significant ($P > 0.05$) differences were perceived in the particle sizes of the different cream cheeses (results not shown).

The CBN-stabilized cream cheeses were also found to be less sticky than the cream cheeses made with the individual stabilizers. A decrease in stickiness values with an increase in elasticity of a material is in accordance with the Dahlquist criterion (Dahlquist, 1969). The firmer structure of the CBN-stabilized cream cheeses was probably due to the presence of a CBN gel in the aqueous phase that helped to provide additional structural rigidity in contrast to the systems formed by the individual stabilizers. The CBN-stabilization probably

made a greater contribution to the firmness of cream cheese than the weak gels formed by XG, or the viscous solutions formed by GG or LBG within the aqueous phase of cream cheese.

Several studies have indicated that addition of XG to skim milk results in phase separation at the natural milk pH (i.e., pH ~ 6.6 ; Hemar et al., 2001; Aichinger et al., 2007). In cream cheese, stabilizers are added after the formation of the acid-induced gel, when caseins are close to their isoelectric point. At this pH (~ 4.6) self-association of caseins is strongest and incompatibility between caseins and XG is likely increased (Syrbe et al., 1998). However, in cream cheese it is unlikely that any incompatibility leads to an overall phase separation, as the protein is already a gel matrix as well as the high viscosity of the continuous phase prevents the coalescence of the dispersed phase where the stabilizers are located (Bot and Vervoot, 2006). However, more studies should be conducted to better understand the location and types of molecular interactions between stabilizers and caseins in the cream cheese system.

CONCLUSIONS

The type of stabilizer used to make cream cheese had an effect on its texture and thermal behavior. The use of an acidified model system helped to clarify the effect of added stabilizers in the cream cheese system. Distinct differences were observed between the rheological properties of individual stabilizer solutions (XG, GG, or LBG) and the CBN of all 3 stabilizers. The CBN solution formed a strong, thermally reversible gel, the

xanthan solution formed a weak gel that was not greatly affected by temperature, and the individual solutions of galactomannans behaved as entangled polymer solutions at all temperatures in the range from 5 to 80°C. It is possible that the presence of a stabilizer gel network in the aqueous phase of the XG- and CBN-stabilized cheeses helped maintain the structure of the system at high temperatures. The rheological behaviors of the different stabilizers in solution were similar to the behavior observed in the cream cheeses manufactured with these stabilizers. The cream cheese made with a CBN of the 3 stabilizers had the highest stiffness and hardness values due to the synergistic interaction between XG and galactomannans that resulted in gelation of this stabilizer blend within the aqueous phase of the cheese. Selection of an individual stabilizer or a CBN could be used to alter the texture and sensory properties of cream cheese. For example, compared with a CBN of stabilizers, the use of XG alone as a stabilizer produced softer and stickier cream cheese that was also easier to spread.

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