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Increasing Stringiness of Low Fat Mozzarella Cheese Using Polysaccharides

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INCREASING STRINGINESS OF LOW FAT MOZZARELLA CHEESE USING POLYSACCHARIDES

by

Erik N. Oberg

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF FOOD MICROBIOLOGY AND SAFETY

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UTAH STATE UNIVERSITY

Logan, Utah

2013
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ABSTRACT

Increasing Stringiness of Low-Fat Mozzarella Cheese using Polysaccharides

by

Erik N. Oberg, Master of Food Microbiology and Safety
Utah State University, 2013

Major Professor: Dr. Donald J. McMahon
Department: Nutrition, Dietetics and Food Sciences

We examined the ability of polysaccharides to function as fat mimetics in low-fat (LF) mozzarella string cheese to improve functionality by acting like fat globules to separate protein fibers during cheese extrusion. Low-fat mozzarella cheese curd made from 273 kg of 0.7% fat milk was salted at a rate of 10 g/kg then divided into 3.6-kg batches that were hand-stretched in 5% brine at 80°C and formed into a homogeneous mass. The hot cheese was hand mixed with a hot 80°C polysaccharide slurry, placed into a small piston-driven extruder and then forced through a 16-mm die to form the string cheese. Extruded string cheese was cut manually into approximately 15-cm lengths.

From preliminary trials using starches (waxy corn, waxy rice, and instant tapioca starch), xanthan and guar gums, and polydextrose, we determined that LF string cheese made using xanthan gum most closely resembled commercial string cheese. LF cheese was then made using a 10% xanthan gum slurry added at 0.25%, 0.5%, 1.0%, 1.5%, and
2.0% (wt/wt) levels. Cheeses were analyzed for fat, salt, pH, and moisture. After 2 wk of 4° C storage, the cheese was analyzed for extent of stringiness by pulling apart the cheese longitudinally, visually observing and photographing the size, length and appearance of individual strings of cheese. Hardness was determined using a Warner-Bratzler shear test. A consumer liking test was conducted after 2 and 8 wk storage time at 6° C.

At 2-wk storage, using a hedonic scale (1 to 9) for overall liking, the LF string cheese with 1% added xanthan slurry (score = 6.8) was liked more (P<0.05) than a retail comparison string cheese (score = 6.2) while, LF cheese with no added gum scored lower (score = 5.9). When considered on a Just-About-Right (JAR) scale, 71% of panelists scored the LF cheese with added xanthan (1%) as having the right texture, while only 49% did so for the commercial retail cheese. The control LF cheese with no added xanthan gum was considered too firm. At 8-wk storage, LF string cheese with 1% added xanthan slurry (score = 6.4) was liked more (P<0.05) than a retail string cheese (score = 6.1). The control LF cheese with no added xanthan gum scored lower (score = 5.7).

When considered on a JAR scale, most of the panelists scored the LF cheese with added xanthan gum (1%) as having the right texture, while only some did so for the retail cheese. The LF control cheese with no added gum was considered too firm. Using a visual comparison, adding the xanthan gum slurry produced greater fiber formation with the longest and most complete string separation. After 8 wk storage, the LF cheeses had softened extensively with fracture stress for LF cheese decreasing from 12 to 20 kg at 2 wk to 1.5 to 3 kg at 8 wk. Extent of stringiness also decreased during storage.
PUBLIC ABSTRACT

Increasing the Stringiness of Low-fat Mozzarella Cheese using Polysaccharides

Because of its lower fat content, low-fat mozzarella cheese is not suitable for making string cheese because it is too firm and lacks stringiness compared to regular string cheese. We investigated the use of adding polysaccharides, which are long carbohydrates, into the low-fat cheese after the cheese has been heated in hot water to form a smooth mass of hot mozzarella cheese, and then forcing the cheese-polysaccharide through an extruder to form the string cheese. Initial trials used various polysaccharides including starches and gums and the best cheese, with most stringiness, was the low-fat string cheese with xanthan gum.

We then tested the cheeses after 2 and 8 week by measuring its hardness, the extent of strings of cheese that could be pulled from a stick of cheese, and how people rated it for texture and overall liking compared to string cheese purchased at a local supermarket. The low-fat string cheese that was liked the best was that containing 1% of a 10% xanthan gum slurry added to the cheese. This cheese had similar liking and texture scores to the retail string cheese, although they did become softer with less stringiness when stored for 8 weeks.

This research opens up a way for manufacturers of string cheese to be able to include low-fat versions of mozzarella string cheese in the products that are sold in the retail market or for use in the school lunch program. Thus providing an alternative that would help meet nutritional guidelines regarding fat content in our diets while still being a good source for protein and calcium.
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My wife, Sammy Oberg.
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LITERATURE REVIEW

String Cheese

Low moisture part skim (LMPS) mozzarella string cheese is considered a snack cheese. It is made by cooking and stretching mozzarella cheese and then forcing that cheese through a die in order to align the protein fibers parallel to each other so that they can be peeled off (Taney et al. 1992). String cheese sales continue to grow in terms of dollars and units (Mayer, 2011). It is a popular snack among children and is increasing in popularity among adults. With a shift in snack foods to lower calories and lower fat options, a LF (LF) alternative for mozzarella string cheese may help continue improved sales (Duboc et al. 2001).

In LMPS string cheese during heating and stretching, fat globules form channels between the proteins which allow protein fibers to form and separate giving the cheese its stringiness (Taneva et al. 1992). Removing fat from mozzarella cheese decreases fiber formation because protein strands fuse together during stretching and extruding, and the protein-protein interactions increase leading to a loss of strand formation or stringiness (Mulvaney et al. 1997). Given that stringiness is a favorable characteristic of mozzarella string cheese, it must be preserved when removing the fat from the cheese.

Other considerations when making LF string cheese are its hardness and color. Many people consume string cheese by just biting it instead of pulling off strings, so any increase in hardness of the cheese can also be important. Another undesirable characteristic of LF mozzarella cheese is the perceived loss of whiteness due to the loss of light scattering from the fat globules. One way this problem can be overcome is by adding titanium dioxide (Kosikowski and Brown, 1969). Fat replacers such as
polysaccharides have been used to make LF cheese by adding them to milk before coagulation, usually to increase moisture content, which can improve melting properties, and microstructural properties (McMahon et al., 1996). Starches have also been added to hot mozzarella cheese curd during stretching to modify its baking properties (Barz and Durkin, 1996), but there have not been studies conducted using polysaccharides as fat replacers in LF string cheese.

**Effect of Fat Removal on Cheese Functionality**

Consumer demand warrants development of reduced-fat and LF cheese with the characteristics of full-fat cheese, particularly flavor and texture. Unfortunately most of these products fall short of replicating the properties of full-fat cheese. As fat percentage is reduced there is an increase in moisture and protein content of cheese, since fat must be replaced by other chemical components of the cheese. Usually moisture will not completely replace removed fat so protein content goes up resulting in an increase in hardness of the unmelted cheese (Rudan et al., 1999).

Removing fat from Mozzarella cheese results in fewer interruption sites in the protein matrix, thus, a more dense protein matrix is created. This decrease in fat allows more compaction of the protein network structure during stretching since there are not sufficient fat globules to keep the casein strands apart as the curd is formed (Fife et al., 1996). In addition, the remaining fat globules incorporated within the protein matrix are usually smaller than in full-fat cheese (Mistry and Anderson, 1993). This results in a decrease in meltdown when the cheese is heated (McMahon et al., 1993). Generally, LF Mozzarella has a harder body, along with poor meltability and undesirable browning characteristics when cooked (Fife et al., 1996; Rowney et al., 1999).
Factors that Affect Functionality (Melt)

Fat, moisture level, and calcium concentration all affect the functionality of Mozzarella cheese. Joshi et al. (2004) showed that reducing the calcium levels in part skim Mozzarella cheese (from 0.65% to 0.35%) increased meltability and resulted in a more hydrated protein matrix. In addition, curd pH affects meltability by influencing the binding of calcium to casein. In string cheese, the optimal condition for stretching falls within a pH range of 5.2 to 5.4 (Kimura et al., 1992). Taneya et al. (1992) found that changes in the pH had greater effects on rheological properties than the moisture content with the flowability of cheese curds decreasing as pH dropped from 5.9 to 5.4 to 5.0. It also appears that one of the key factors in producing lower fat cheeses with acceptable characteristics (similar to full-fat cheese properties) is maintaining the same moisture in nonfat substance ratio as found in full-fat cheeses (Broadbent et al., 2001).

Modifications in manufacturing procedure have been utilized to make modest improvements in LF Mozzarella cheese (Merrill et al., 1994). Pre-acidification of the milk also results in calcium reduction, and this has been observed to decrease post melt-chewiness of LF Mozzarella (Metzger et al., 2001). Tunick et al. (1993) found that a LF Mozzarella having textural and melting properties comparable with those of a normal high-fat cheese can be prepared using homogenized milk and a lower cook temperature. Fife et al. (1996) showed that increasing the moisture content of LF Mozzarella cheese also improved its functionality. Another option may be to increase hydration of the protein network and better emulsify the fat, particularly in low calcium cheeses (Joshi et al., 2004). Addition of emulsifying salts holds some promise to improve the meltability of nonfat Mozzarella cheese. Mizuno and Lucey (2005) found that adding trisodium
citrate increased meltability while added tetrasodium pyrophosphate decreased meltability in nonfat pasta filata cheese.

**Fat Replacers in Lower Fat Mozzarella Cheese**

To increase meltability, an approach is to use starter cultures that produce exopolysaccarides (EPS) to bind additional water in cheese matrix. Perry et al. (1997) showed that use of EPS-producing cultures resulted in LF Mozzarella cheese with increased moisture content and improved meltability. Zisu and Shah (2006) also found that utilization of EPS-producing cultures in Mozzarella cheese manufacture improved shred fusion, meltability, and a reduction in surface scorching during cooking. Using confocal scanning laser microscopy, Hassan et al. (2002) observed EPS in feta cheese as thick sheets filling pores in the protein network.

Water-soluble fat replacers, usually polar molecules, based on microparticulated carbohydrates and microparticulated protein (fat mimetics) have been used to replace fat in Mozzarella cheese. Fat mimetics act through binding extra water, which creates a lubricity similar to full-fat products, however they cannot replace the non-polar properties of fat such as flavor carrying capacity (McMahon et al., 1996). Starch and other fat mimetics impart softness to products primarily by entrapping moisture but may not interact directly with the other components (Lucca and Tepper, 1994). It has been hypothesized that water binds directly to the fat replacer allowing the fat replacer to interfere with shrinkage of casein (CN) matrix (Koca and Metin, 2004), which lowers the force needed to expel water from the curd particles (Madadlou et al., 2007).

McMahon et al. (1996) used fat replacers to manufacture LF Mozzarella cheese with some success. All fat replacers yielded an increase in cheese moisture but only two,
Stellar™ (carbohydrate-base) and Simplesse™ (protein-based) initially showed any improvement in cheese meltability although after 21 d of storage they were similar to the control cheese containing no fat replacer. They also showed that particle size and distribution of the fat replacer in the protein matrix appeared to play a role in its effectiveness. The use of another fat replacer, Salatrim™, a tailored fatty acid triglyceride used as a fat substitute, had no affect on reduced-fat Mozzarella cheese functionality (Rudan et al., 1998). Mistry (2001) blended microcrystalline cellulose, carrageenan, and NDM in cheese milk in a reduced-fat Cheddar cheese. He noted the cheese structure was softened by interference of the casein-casein interactions due to these particles becoming embedded in the curd matrix.

One problem with the use of fat replacers or fat mimetics may be that they do not behave like fat when heated, the common state of Mozzarella cheese since it is consumed as a cooked product. Fat replacers or fat mimetics may also not perform adequately when going through the cooker/stretcher to keep the protein strands separated, particularly essential for development of string cheese functionality. As a result of the lack of success in using fat replacers, fat mimetics or fat substitutes to improve the functionality of reduced-fat and LF Mozzarella cheeses, the use of gums, some of which are closer in composition to EPS, may hold some promise.

**Starch and Gums in Lower Fat Cheese**

Aside from using exopolysaccharide-producing starter bacteria or incorporating fat mimetics into the cheese matrix, another possibility is the addition of gums, either microbial (xanthan, gellan, etc.) or plant derived (carrageenans, guar, tapioca, etc.), during cheese manufacture. Rahimi et al. (2007) decreased the hardness of cheese body
in LF Iranian cheese by using gum tragacanth as a fat replacer but a softness defect occurred during aging. Volikakis et al. (2004) reported the texture of a LF brined white cheese improved by the addition of oat-β-glucan concentrates. Sipahioglu et al. (1999) used tapioca starch and lecithin in reduced-fat and LF feta cheese, and found that improved texture (decreased hardness) in the reduced-fat cheese. Using a scanning electron microscope, they also observed that the starch and lecithin produced full-fat-like structures more effectively at the reduced-fat level (14%) then the LF level (10%).

Mounsey and O’Riordan (2001) studied the effect of different native starches on the properties of imitation cheese and found hardness increased with wheat, potato, and maize starches but reduced by waxy-maize or rice starches. When McMahon et al. (1996) used a variety of fat replacers to improve LF Mozzarella texture, the one fat replacer that exhibited the greatest improvement in moisture retention and meltability was Stellar™ 100X, a mixture of modified corn starch and xanthan gum.

Addition of other microbial and/or plant derived gums could improve the functionality of Mozzarella cheese by binding additional water and even forming voids or channels that mimic those found in the microstructure of full-fat Mozzarella cheese. One such gum is xanthan, a high molecular weight heteropolysaccharide with a cellulose skeleton and trisaccharide side chains of D-mannose and D-glucuronic acid on the glucose residues. Many of the properties of xanthan are the result of its double helical conformation when in solution since the trisaccharide side chains stabilize the conformation (Ricciardi and Clementi, 2000). Another commonly added gum is gellan, a linear polymer made up of repeating tetrasaccharide units, which has also been used in foods as a gel forming, stabilizer and suspension agent (Ricciardi and Clementi, 2000).
Charges on the polysaccharides also appear to play an important role since this determines how they will interact with the protein matrix. Experiments have shown that linear neutral polysaccharides contribute to viscosity but not to elasticity. On the other hand, negatively-charged polysaccharides contribute to the elasticity, but not to the viscosity, since they interact with the positively-charged casein particles by electrostatic interactions, reinforcing the strength of the network (Duboc and Mollet, 2001).

Little is known concerning the affect of polysaccharides on functionality during the cooker/stretcher phase of string cheese production (Corredig et al., 2011). It is important that added fat replacers, mimetics or EPS developed during fermentation enhance strand formation by inhibiting complete casein fusion during this processing step. This research investigates the effect of various polysaccharides and starches on the development of stringiness during this critical processing in string cheese.

**HYPOTHESIS**

Polysaccharides can act as fat mimetics during string cheese extrusion to aid in fiber formation by physically blocking protein fusion and allowing protein strands to form.

**OBJECTIVES**

1. Make LF string cheese using a variety of polysaccharides to determine which will have the most potential for producing string cheese with the longest strings.
2. To determine the effect of polysaccharide level on consumer acceptability, and on the physical attributes of LF string cheese.
MATERIALS AND METHODS

Polysaccharides

The following starches used in initial cheese making trials were: waxy rice starch, waxy corn starch and instant tapioca starch. All these starches were obtained from National Food Starch (Bridgewater, NJ). Other polysaccharides used in cheese making trials were xanthan gum (Grindsted® Xanthan 80), guar gum, and polydextrose. All of these additives were obtained from Danisco (Madison, WI).

Each polysaccharide was hydrated using distilled water into a 10% (wt/vol) slurry, stirred until it was in solution, and then gently heated in a microwave to achieve a homogeneous consistency. In the first preliminary trial 10% (wt/vol) slurries of waxy rice starch, waxy corn starch and instant tapioca were added into the molten cheese to a final concentration of 8% (wt/wt) during the cooking/stretching step. In the second preliminary trial 10% (wt/wt) slurries of instant tapioca starch, xanthan gum, guar gum and a 50/50 guar/xanthan gum mixture were used, as well as polydextrose as a 25% (wt/wt) slurry. All slurries were made just prior to cheese addition.

For the trial in which xanthan gum was exclusively used the 10% (wt/wt) slurry was added at different concentrations into the cheese curd at the cooking/stretching step: 0% (control cheese), 0.25%, 0.5%, 1.0%, 1.5% and 2.0% (wt/wt).

Cheese Manufacture

Pasteurized 0.7%-fat milk (273 kg) was obtained from the Gary Haight Richardson Dairy Products Laboratory and made into cheese curd following the procedure of Merrill et al. (1994) with several modifications. The starter culture for all cheese trials was Streptococcus thermophilus TS-20D (DSM, Logan, UT).
A combination of TiO$_2$ (28 g TiO$_2$ paste diluted 1:10 in distilled water per vat) and annatto (1 ml diluted 1:20 in distilled water) were added to improve the white opaqueness of the LF string cheese. The milk was pre-acidified with 5% (wt/wt) acetic acid to pH 6.3, at which point the starter culture used was added. In addition, the cooking/stirring temperature was lowered to 94°F instead of the usual 102°F. When the curd pH reached 5.25, the whey was drained. Curd was washed with cold water by filling the vat to the top of the curd level with cold water and waiting until the curd temperature reached 60°F, to stop any further acid production. Following draining of the water, curd was salted at a rate of 10 g NaCl/kg of curd then divided into 3.6-kg batches.

Each curd batch was hand-stretched in 5% NaCl (wt/wt) hot brine (80°C) and formed into a homogeneous mass. Then the hot cheese was hand mixed in a small vat with a hot (80°C) polysaccharide slurry at the required level. The slurry was kneaded into the molten cheese. The mixed cheese containing the added slurry was placed into a small piston-driven heat-jacketed extruder (Figure 1) and forced through a 16-mm die to form the string cheese and cut manually into approximately 15-cm lengths (Figure 2). The cheese was put into an ice brine solution of 5.0% NaCl (wt/wt) for 10 minutes. Each lot of string cheese was stored in vacuum-sealed packaging at 6°C.

**Experimental Design**

**Trial 1 - Use of starch slurries.** In the initial trial, cheeses were made with starches that have been previously studied as fat mimetics in renneted milk gels (Brown et al. 2012). Ten percent (wt/vol) slurries of waxy rice starch, waxy corn starch and instant tapioca were added to individual batches of molten LF curd to a final concentration of 8% (wt/wt) just prior to the extrusion step. Cheese composition was
Figure 1. Loading cheese into the string cheese extruder.

Figure 2. String cheese being extruded and manually cut before cooling in an ice-brine bath.
determined after 1 wk of storage at 6°C. Stringiness of the cheese was evaluated after 2 wk storage. Starches that produced the longest strings were selected for additional trials.

**Trial 2 - Use of gums and polydextrose.** Cheeses were made with 10% (wt/wt) slurry of instant tapioca starch added to the hot cheese curd to a final concentration of 8% (wt/wt). This was the only starch from the initial trial that showed acceptable results. In addition, 8% (wt/wt) slurries of xanthan gum, guar gum, and a 50/50 guar gum slurry/xanthan gum slurry mixture were added to the hot cheese curd to a final concentration of 2% (wt/wt) just prior to the extrusion step. A 50% (wt/wt) polydextrose solution was also added to a final concentration of 10% (wt/wt). Cheese chemical composition was determined after 1 wk storage at 6°C. Stringiness and hardness were evaluated following 2 and 4 wk storage at 6°C and compared to commercial LMPS string cheese as a control. Cheeses were also examined using laser scanning confocal microscopy to determine the distribution and retention of the polysaccharides in the cheese.

**Trial 3 - Use of xanthan gum.** Two trials were run in which the cheese was made with a 10% (wt/wt) slurry of xanthan gum added to the hot cheese curd to a final concentration of 0.25%, 0.5%, 1.0%, 1.5%, or 2.0% (wt/wt) just prior to the extrusion step. Cheese chemical composition was determined after 1 wk of storage at 6°C. All cheeses for both replicates were analyzed for stringiness, hardness, and consumer acceptability for flavor and texture following 2 and 8 wk of 6°C storage. Cheese microstructure was also examined using laser scanning confocal microscopy at 2 wk.
**Chemical Analysis**

After one week of storage at 6°C, each cheese in each trial was analyzed for fat using the Babcock Method (AOAC Official Method 920.111B-C). Salt was determined using the AOAC Official Method 975.20 Salt in Cheese. The pH was tested by diluting 5 g of cheese in 20 ml of distilled water, stomaching for 1 min at 260 rpm, and then the pH was measured. Moisture content was determined in triplicate by weight loss using a microwave oven (CEM Corp., Indian trail, NC) at 100% power with an endpoint setting of <0.4 mg weight change over 2 s.

**Stringiness**

Stringiness was measured objectively by comparing the different LF cheeses to each other and to commercial LMPS mozzarella string cheese by visual observation of the strings (Taneva et al., 1992). Cheese strings were pulled from the 15-cm long string cheeses longitudinally by hand and then visually observed, and photographed for size and appearance of individual strings. Cheeses that produced strings with smaller diameters and greater lengths were considered to have more stringiness.

**Hardness**

Hardness was measured using a shear test to simulate a person biting into the cheese by measuring resistance load (Bhaskaracharya and Shah, 1999) with modifications from a beef rib steak shear test (Caine et al., 2003). A Warner-Bratzler Blade with a 3-mm round edge mounted on a TA XT Plus Texture Analyzer (Texture Technologies, Scarsdale, NY) was lowered into the cheese from a height of 18 mm perpendicular the strings (cross section orientation) at 1 mm/sec (Figure 3) and load was measured over time. Results were plotted as g-force/distance traveled over time. In
addition to LF cheeses containing starches and gums, commercial string cheeses were also tested.

**Microstructure**

Observations on the distribution of polysaccharides in the cheese matrix were made using confocal laser scanning microscopy. Cheese samples were frozen using liquid nitrogen and thin slices (1 cm x 1 cm x 0.5 mm) were cut perpendicular to the protein fibers using a microtome cryostat (International Equipment Company (Damon), Needham Heights, MA). The slices were fixed by immersing them in osmium tetroxide vapor in an enclosed petri dish containing a filter paper soaked in an osmium tetroxide solution for 18 h in a fume hood. The cheese slices were then treated with 0.5% (wt/vol)
Figure 3. Example of shear test used to determine hardness of string cheeses
periodic acid for 20 min to produce aldehyde groups in the embedded polysaccharides. Cheese samples were then washed with several exchanges of deionized water. Washed cheese samples were immersed in a 0.1% (wt/vol) acriflavin HCl solution while being microwaved (Model 3470, Ted Pella Inc., Redding, CA) under a vacuum for 4 cycles of 2 min on and 2 min off at 31°C. This procedure attaches the fluorophore to aldehyde groups of the polysaccharides (McManus, et al. 2009). The cheese samples were then immersed in 0.1% (wt/vol) Rhodamine B and again microwaved under vacuum as previously described. The cheese samples were washed with deionized water, mounted on a glass slide and covered in glycerol/gelatin solution then covered with a glass cover slip carefully so as to not trap any air bubbles under the cover slip (Horobin and Kiernan, 2002).

Samples were imaged on a laser scanning confocal microscope (MRC 23; Bio-Rad Laboratories Inc., Hercules, CA) with a Kr/Ar laser exciting the acriflavine at 488 nm and the rhodamine B at 568 nm. Sample emissions were from 488 to 650 nm and 550 to 750 nm, respectively, and exclusion filters of 512 to 532 nm and above 585 nm were used to capture the fluorescent signals of acriflavine bound to oxidized starch and the Rhodamine B bound to protein. Images were false colored with protein as red-orange and starch as yellow-green (Brown et al., 2012).

**Sensory**

After 2 and 8 wk of storage time, consumer sensory panels were conducted at the Utah State University Food Sensory Kitchen using volunteers from the community with a target minimum of 60 panelists (actual numbers were 79, 104, and 103 for the three
tests). The LF cheeses were compared to a LMPS commercial string cheese, which was purchased from a local supermarket the day before the test. Each panelist was given 15-mm of each cheese in a randomized order. The tests were conducted using a 9-point Hedonic liking scale according to flavor, in which 9 = Like Extremely, 8 = Like Very Much, 7 = Like Moderately, 6 = Like Slightly, 5 = Neither Like nor Dislike, 4 = Dislike Slightly, 3 = Dislike Moderately, 2 = Dislike Very Much, 1 = Dislike Extremely. A Just About Right (JAR) texture scale was also utilized for the cheese samples in which the panelists were given the options of just right, too firm, and too soft.

RESULTS AND DISCUSSION

Trial 1 - Use of Starch Slurries

The moisture, fat, pH, and NaCl analyses for the cheese are found in Table 1. As expected the moisture for the LF cheeses were higher (~60%) compared to a commercial LMPS mozzarella string cheese (51%). Pre-acidification of the milk before renneting to pH 6.3, eliminating the curd cook step, and washing the curd with 10°C water allowed production of a LF cheese (6% fat) with sufficient moisture so that it was not too hard and rubbery. Salt and pH of the cheeses were within normal ranges (Table 1).

Table 1. Composition of low-fat string cheese for Trial 1.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Moisture %</th>
<th>Fat %</th>
<th>pH</th>
<th>Salt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>58.51</td>
<td>6</td>
<td>5.16</td>
<td>1.83</td>
</tr>
<tr>
<td>Waxy Rice</td>
<td>59.87</td>
<td>5.5</td>
<td>5.25</td>
<td>2.28</td>
</tr>
<tr>
<td>Waxy Corn</td>
<td>58.75</td>
<td>6</td>
<td>5.15</td>
<td>1.87</td>
</tr>
<tr>
<td>Instant Tapioca</td>
<td>59.95</td>
<td>6</td>
<td>5.26</td>
<td>1.91</td>
</tr>
</tbody>
</table>
Upon visually examining the string formation of all the cheeses from Trial 1 at 2 wk of storage time, the cheese with added instant tapioca starch produced the longest strings with the smallest diameter when peeled off by hand. An example of the tapioca-treated cheese strands can be seen in Figure 4. The control LF cheese with no added polysaccharide had little to no string production upon peeling and when trying to pull strings, the cheese would just fracture. Cheese made with either waxy rice starch or instant tapioca starch had higher moisture contents by 1% than the other cheeses and their pH was also slightly higher (0.1 units). Yet only the cheese containing the instant tapioca starch showed adequate string formation suggesting that there was more to improving string formation than just increasing water binding in the cheese matrix.

From Trial 1 it was concluded that the LF cheese making process incorporating the make procedure modifications (Merrill et al., 1994) was successful in producing
mozzarella string cheese with differences that could be measured and compared. Instant tapioca was the only treatment that compared favorably to the LMPS commercial string cheese so it was incorporated in Trial 2 for comparison to LF cheeses with gum addition.

**Trial 2 - Use of Gums and Polydextrose**

Cheese composition from Trial 2 are found in Table 2. The moisture levels in Trial 2 were about 1% higher than the moisture levels of cheeses in Trial 1. Upon visual inspection and pulling strings by hand of Trial 2 cheeses at 2 wk storage, cheeses that produced the strings with the smallest diameter and greatest length were cheeses with either xanthan gum added or the xanthan/guar gum mixture (Figure 4). As noted previously, the cheese with no added polysaccharide exhibited very little to no string formation.
Of the cheeses with added polysaccharides the cheese with added polydextrose had the least string production and was similar to the cheese with no added polysaccharides. After 4 wk of storage time, both string length decreased and string diameter increased for all treatments used in the LF cheese. The string formation decreased as seen in Figure 5. The cheeses made with xanthan gum still showed the best string formation after 4 wk. The control cheese containing no added polysaccharides fractured readily when strings were pulled.

**Table 2.** Composition of low-fat string cheese for Trial 2.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Moisture %</th>
<th>Fat %</th>
<th>pH</th>
<th>Salt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>60.51</td>
<td>6</td>
<td>5.5</td>
<td>1.75</td>
</tr>
<tr>
<td>Inst. Tapioca</td>
<td>62.34</td>
<td>6</td>
<td>5.41</td>
<td>1.24</td>
</tr>
<tr>
<td>Guar Gum</td>
<td>60.53</td>
<td>6</td>
<td>5.37</td>
<td>1.99</td>
</tr>
<tr>
<td>Xanthan</td>
<td>60.42</td>
<td>6</td>
<td>5.56</td>
<td>1.99</td>
</tr>
<tr>
<td>Guar/Xanthan</td>
<td>61.13</td>
<td>6</td>
<td>5.4</td>
<td>1.88</td>
</tr>
<tr>
<td>Polydextrose</td>
<td>60.78</td>
<td>5.5</td>
<td>5.25</td>
<td>1.61</td>
</tr>
</tbody>
</table>

Low-fat string cheese made with xanthan gum had the same moisture level as the other cheeses but its pH was considerably higher suggesting it supplies some type of buffering effect during acid production. Cheese containing the instant tapioca starch had a higher moisture content, by almost 2% over the other cheeses, yet the increased moisture did not seem to translate into better string formation at either 2 or 4 wk of storage. This cheese also had less salt which may have some effect on stringiness. It appears that binding additional water does mean there will be improved stringiness in LF string cheese.
Texture analysis. On examining the load versus distance curves obtained during the shear test of commercial LMPS string cheese (Figure 6) it was observed that the LMPS string cheeses deformed under the force of the blade and fractured at between 8 and 11 mm of penetration. In comparison, the LF string cheeses exhibited a more brittle fracture at 12 to 14 mm that was manifest by a sharp increase in force (peak) followed immediately by a sharp drop off in force (Figure 7). The commercial cheese deformed and compressed more than it fractured as manifest by the lack of a sharp spike in the force measured and a broader shoulder after the peak was observed (Figure 6). Only Frigo brand string cheese showed a rapid decrease after the peak characteristic of the cheese body fracturing as the blade continued to move down.

Figure 5. String length and width assessment at 4 wk storage time, after strings pulled longitudinally by hand.
The results of the texture analysis showed that xanthan gum and the mixture of guar and xanthan gums produced texture profiles that were the closest to those produced by LMPS commercial cheese as shown by a wider shoulder following the peak. The cheeses with added tapioca starch or polydextrose fractured more than they deformed and had steeper declines following the fracture event than either the commercial or xanthan cheeses. The sharp peak on the texture curves indicates that the LF cheeses are brittle (Bhaskaracharya and Shah, 1999).

**Microstructure.** The images obtained from confocal laser scanning microscopy (Figures 8 and 9) show the distribution of the polysaccharides throughout the cheese matrix. When comparing the two samples with different polysaccharides (instant tapioca and polydextrose) the cheese with added instant tapioca starch (Figure 8) had better distributed and less congregation than those in the cheese with added polydextrose.
Figure 6. Load versus distance curves from the shear test of commercial LMPS string cheeses.
Figure 7. Load versus distance curves from the shear test of low-fat string cheese with added polysaccharides from Trial 2.
**Figure 8.** Microstructure of low-fat string cheese containing instant tapioca starch (Trial 2), grey areas are protein matrix, black is serum and/or fat globules, and white area is polysaccharide.

**Figure 9.** Microstructure of low-fat string cheese containing poledextrose (Trial 2), grey areas are protein matrix, black is serum and/or fat globules, and white area is polysaccharide.
(Figure 9). The white areas in the figures are the polysaccharides, the gray is the protein matrix, and the black is the serum phase/fat globules.

**Trial 3 - Use of Varying Xanthan Gum Concentrations (Rep. 1)**

The moisture, fat, pH, and salt analyses for Trial 3 (replicate 1) LF cheeses containing varying concentrations of xanthan gum are found in Table 3. The moisture levels are fairly similar among the cheeses containing different concentrations of xanthan gum. The moisture is about 1% higher than in previous LF string cheese trials (1 and 2) and the pH in all the cheeses that contain xanthan gum is also higher, again suggesting that xanthan has some buffering effect on the cheese. Between xanthan gum concentrations of 0.25 and 1.5% the pH remains consistent but at 2% xanthan gum the cheese pH is noticeably higher.

Cheeses with added xanthan gum produced longer strings with smaller diameters when compared to LF cheeses made with starch in previous trials. The LF control cheese had little to no string formation. After 2 wk storage, string formation was similar between LF cheeses with xanthan gum (Figure 10). The cheeses with concentrations of

**Table 3. Composition of low-fat string cheese from Trial 3 (replicate 1)**

<table>
<thead>
<tr>
<th>Xanthan Conc.</th>
<th>Moisture</th>
<th>Fat %</th>
<th>pH</th>
<th>Salt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00%</td>
<td>60.5</td>
<td>6</td>
<td>5.35</td>
<td>1.75</td>
</tr>
<tr>
<td>0.25%</td>
<td>61.3</td>
<td>6</td>
<td>5.41</td>
<td>1.8</td>
</tr>
<tr>
<td>0.50%</td>
<td>60.5</td>
<td>6</td>
<td>5.37</td>
<td>1.99</td>
</tr>
<tr>
<td>1.00%</td>
<td>60.4</td>
<td>6</td>
<td>5.41</td>
<td>1.99</td>
</tr>
<tr>
<td>1.50%</td>
<td>61.1</td>
<td>6</td>
<td>5.4</td>
<td>1.9</td>
</tr>
<tr>
<td>2.00%</td>
<td>61</td>
<td>5.5</td>
<td>5.53</td>
<td>1.88</td>
</tr>
</tbody>
</table>
0.5% to 1.0% had slightly better string formation, producing string with smaller diameters. After 8 wk of storage the string formation decreased in all cheeses (Figure 11). The cheeses with 0.5% and 1.0% added xanthan gum slurry produced the longest strings with the smallest diameter. Control cheese with no added xanthan gum had little to no string formation. The cheese with 2.0% added xanthan still showed little to no string formation after 8 wk of storage. As with Preliminary Trial 2, string formation decreased with storage time as seen when comparing Figures 10 and 11.

**Texture Profile Analysis.** When comparing the load versus distance texture profiles of commercial LMPS string cheeses to LF string cheeses with added xanthan gum an improvement in the LF cheese was observed compared to Trial 2 LF string cheeses. The LMPS cheeses deformed under the force of the blade and fractured between

![Figure 10](image.png)

**Figure 10.** String length and width assessment at 2 wk storage time, after strings pulled longitudinally by hand for Trial 3, Rep. 1
Figure 11. Photographs of string formation at 8 weeks storage Trial 3, Rep. 1.
Figure 12. Load versus distance curves from the shear test of Trial 3, Rep 1 at 2 wk string cheese containing varying concentrations of xanthan gum.

8 and 11 mm penetration (see Figure 6). The LF cheeses when analyzed at 2 wk of storage exhibited a more brittle fracture between 9 and 12 mm that was manifest by a sharp peak in force followed by a sharp drop off in force as shown in Figure 12. The commercial cheese deformed and compressed more than it fractured as manifest by the lack of a sharp spike in the force measured.

After 8 wk of storage time the LF string cheeses with xanthan gum addition had a decrease in firmness and fracture intensity (Figure 13). All LF cheeses became softer as seen by the decrease in force. The addition of xanthan gum produced cheeses with more similar TPA curves to those of commercial string cheese.

Consumer Panels. The data obtained from consumer panel conducted indicated that the LF cheeses with added xanthan gum were preferred over the LF control cheese.
with no added xanthan gum. At 2 wk of storage, the LF cheeses with 1.0% and 1.5% xanthan gum scored higher on the hedonic liking scale than the commercial control (Table 4) with scores of 6.76 and 6.41. The cheese with 1.0% xanthan gum had the best texture with a JAR score of 71% and the LF control had the worst texture with a score of 23% tending to be too soft according to the consumers (Table 5).

**Trial 3 - Use of Varying Xanthan Gum Concentrations (Rep. 2)**

The moisture, fat, pH, and NaCl analyses from Trial 3, Rep. 2 are found in Table 6. After 2 wk of storage time, as in the first trial, the LF cheeses with added xanthan gum at varying levels had good string formation and were very similar to each other. The control cheese with no added xanthan gum had little to no string formation.
Table 4. Hedonic liking scale averages of panelists for string cheese at 2 weeks storage time for Trial 3, Rep. 1.

<table>
<thead>
<tr>
<th>Attribute Description</th>
<th>No Added Xanthan</th>
<th>0.25%</th>
<th>0.50%</th>
<th>1.0%</th>
<th>1.5%</th>
<th>Retail Cheese</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liking</td>
<td>c</td>
<td>bc</td>
<td>bc</td>
<td>a</td>
<td>ab</td>
<td>bc</td>
<td>5.86</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>6.15</td>
<td>6.76</td>
<td>6.41</td>
<td>6.18</td>
<td>6.18</td>
<td>0.0003</td>
</tr>
</tbody>
</table>

Scores within rows with the same letter were not significantly different.

Table 5. Just-about-right averages for low-fat string cheeses containing xanthan gum at 2 wk storage time, Trial 3, Rep. 1.

<table>
<thead>
<tr>
<th>Attribute Description</th>
<th>No Added Xanthan</th>
<th>0.25%</th>
<th>0.50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAR - Texture</td>
<td>Frequency in%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; Center</td>
<td>Center</td>
<td>&gt; Center</td>
</tr>
<tr>
<td>JAR - Texture</td>
<td>1%</td>
<td>23%</td>
<td>76%</td>
</tr>
</tbody>
</table>

Table 6. Composition of low-fat string cheese containing xanthan gum, Trial 3, Rep. 2.

<table>
<thead>
<tr>
<th>Xanthan Slurry Conc.</th>
<th>Moisture %</th>
<th>Fat %</th>
<th>pH</th>
<th>Salt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00%</td>
<td>60.8</td>
<td>6.0</td>
<td>5.53</td>
<td>1.89</td>
</tr>
<tr>
<td>0.25%</td>
<td>60.7</td>
<td>6.0</td>
<td>5.52</td>
<td>1.73</td>
</tr>
<tr>
<td>0.50%</td>
<td>60.5</td>
<td>6.0</td>
<td>5.50</td>
<td>1.78</td>
</tr>
<tr>
<td>1.00%</td>
<td>60.6</td>
<td>6.0</td>
<td>5.49</td>
<td>1.85</td>
</tr>
<tr>
<td>1.50%</td>
<td>60.3</td>
<td>6.0</td>
<td>5.46</td>
<td>1.83</td>
</tr>
<tr>
<td>2.00%</td>
<td>60.0</td>
<td>6.0</td>
<td>5.50</td>
<td>1.86</td>
</tr>
</tbody>
</table>
Texture Profile Analysis. Analysis with TPA of the LF string cheeses was very similar to those in trial 3, Rep 1. The results again indicated that the LF string cheeses at 2 wk of storage exhibited a more brittle fracture between 9 and 12 mm that was manifest by a sharp peak in force followed by a sharp drop off in force similar to Figure 12. After 8 wk of storage time, the LF string cheeses had a decrease in firmness and fracture intensity as seen in chart 4. The cheeses deformed under the force of the blade and the sharp peaks seen at 2 wk storage time were not seen after 8 wk of storage time. The LF cheeses became softer as seen by the decrease in force. The addition of xanthan gum produced cheeses with more similar TPA curves to those of commercial string cheese, but the LF string cheese with added xanthan gum still fractures more than LMPS commercial string cheese.

Consumer Panels. The consumer panel conducted after 2 wk of storage showed that the cheese with 1.0% xanthan gum was the most preferred by the panelists of the LF cheeses with a score of 6.44 (Table 7). The LF control cheese was the least preferred by consumers in both taste and texture tending to be too firm with a score of 5.89 and JAR of 4.01 (JAR score of 3 is ideal). The commercial string cheese was most preferred of all the cheeses, both in taste and texture with a score of 7.27 and a JAR of 2.96. The consumer panel conducted after 8 wk of storage had slightly different results (Table 8). The commercial cheese was preferred most in taste and texture among all cheeses with a score of 6.43 and a JAR of 3.01. The 1.0% xanthan gum cheese was most preferred in
Table 7. Hedonic liking scale averages and just-about-right scores for low-fat string cheeses containing xanthan gum at 2 wk storage time and a retail string cheese, Trial 3, Rep. 2

<table>
<thead>
<tr>
<th>Attribute</th>
<th>No Added Xanthan</th>
<th>0.25%</th>
<th>0.50%</th>
<th>1.0%</th>
<th>1.5%</th>
<th>Retail Cheese</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liking</td>
<td>c</td>
<td>bc</td>
<td>bc</td>
<td>b</td>
<td>b</td>
<td>a</td>
<td>0.0003</td>
</tr>
<tr>
<td>JAR- Texture</td>
<td>a</td>
<td>d</td>
<td>ab</td>
<td>bc</td>
<td>cd</td>
<td>e</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Scores within rows with the same letter were not significantly different.

Table 8. Hedonic liking scale averages and JAR scores for string cheeses at 8 wk storage time Trial 3, Rep. 2.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>No Added Xanthan</th>
<th>0.25%</th>
<th>0.50%</th>
<th>1.0%</th>
<th>1.5%</th>
<th>Retail Cheese</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liking</td>
<td>bc</td>
<td>c</td>
<td>ab</td>
<td>ab</td>
<td>ab</td>
<td>a</td>
<td>0.0003</td>
</tr>
<tr>
<td>JAR- Texture</td>
<td>bc</td>
<td>a</td>
<td>b</td>
<td>b</td>
<td>c</td>
<td>c</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

Scores within rows with the same letter were not significantly different.
taste among the LF cheeses with a score of 6.13. The 1.5% xanthan gum cheese was most preferred for texture among the LF cheeses with a JAR of 2.95. The least preferred for taste and texture was the 0.25% xanthan gum cheese and some described it as having an oxidized taste.

**CONCLUSIONS**

The addition of polysaccharides to LF string cheese increased fiber formation during stretching so that the cheeses were more similar to LMPS commercial string cheese in stringiness. The string formation in the LF cheeses did decrease over time and could be problematic for an extended shelf life. There could be several reasons why this happened. First, the moisture in the channels between the proteins that carried the polysaccharides was absorbed into the protein matrix and the channels were lost. Secondly, it could have been a function of vacuum packaging used for storage of experimental cheeses. The vacuum may have been too strong and some of the moisture from the channels was lost to syneresis. Finally, fusion could have occurred between the polysaccharides and protein matrix. Further research is needed to understand the interactions between the proteins and the polysaccharides especially during storage of string cheese. A solution for the packaging would be to use gas flushing similar to what is done commercially and then the cheese would be packaged with no extra pressure exerted from the packaging.

The TPA helped to measure differences between the experimental LF string cheeses and the commercial string cheeses. The LF cheeses even with added polysaccharides tended to fracture and this would indicate that when pulling strings from
the cheese, the strings will break. The LF cheese also had a higher force exerted on them, which indicates that they are firmer than the commercial cheeses. This is an unfavorable characteristic, but the results are promising in that the LF cheeses with added polysaccharides performed more like commercial cheeses, especially when xanthan gum was used to replace fat.

The confocal laser scanning microscopy method used gave promising results in being able to image the polysaccharides distributed throughout the cheese and visualize the polysaccharides in the protein matrix.

Results from the consumer panels showed that the LF cheeses with added xanthan gum were preferred over LF cheeses with no added polysaccharides. In one consumer taste test, the LF cheese with added xanthan gum was preferred over all other cheeses including the LMPS commercial string cheese. The liking scores for all LF cheeses decreased over time, but the cheeses with added xanthan gum were still preferred over the LF cheeses with no added xanthan. The consumer panel at 8 wk was a little different in that the cheese with no added xanthan was preferred over the cheese with 0.25% xanthan gum. An explanation for this could have been that the cheese had oxidized as indicated by some of the panelist’s comments.

From the data it can be concluded that adding polysaccharides to the LF string cheese improved the stringiness of the cheese as well as the functionality.

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