J. Dairy Sci. 90:4058–4070
doi:10.3168/jds.2007-0121

Texture of Low-Fat Iranian White Cheese as Influenced by Gum Tragacanth as a Fat Replacer

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ABSTRACT

The effect of different concentrations of gum tragacanth on the textural characteristics of low-fat Iranian White cheese was studied during ripening. A batch of full-fat and 5 batches of low-fat Iranian White cheeses with different gum tragacanth concentrations (without gum or with 0.25, 0.5, 0.75, or 1 g of gum/kg of milk) were produced to study the effects of fat content reduction and gum concentration on the textural and functional properties of the product during ripening. Cheese samples were analyzed with respect to chemical, color, and sensory characteristics, rheological parameters (uniaxial compression and small-amplitude oscillatory shear), and microstructure. Reducing the fat content had an adverse effect on cheese yield, sensory characteristics, and the texture of Iranian White cheese, and it increased the instrumental hardness parameters (i.e., fracture stress, elastic modulus, storage modulus, and complex modulus). However, increasing the gum tragacanth concentration reduced the values of instrumental hardness parameters and increased the whiteness of cheese. Although when the gum concentration was increased, the low-fat cheese somewhat resembled its full-fat counterpart, the interaction of the gum concentration with ripening time caused visible undesirable effects on cheese characteristics by the sixth week of ripening. Cheeses with a high gum tragacanth concentration became very soft and their solid texture declined somewhat.
Key words: Iranian White cheese, low fat, gum tragacanth, rheology

INTRODUCTION

Over the last decade, the consumption of low-fat food products has become more than just a trend. Because of an increasing consumer trend for low-fat products, the production of reduced or low-fat cheeses has significantly increased (Mistry et al., 1996; Mistry, 2001; Kavas et al., 2004). Because of the critical role of fat in the flavor, texture, and appearance of food, it quickly becomes obvious that developing low-fat products with a quality matching that of their full-fat counterparts is a fairly difficult task when one is replacing fat with alternative ingredients (Romeih et al., 2002). In cheese, the removal or reduction of fat adversely affects both its flavor and texture (Metzger et al., 2001; Koca and Metin, 2004; Madadlou et al., 2005); low-fat cheeses are usually identified as bland, firm, rubbery, and defective in color (Sipahioglu et al., 1999). To overcome these defects, various suggestions have been made. Increasing the moisture content is the most common proposition to overcome the usual textural defects of low-fat cheeses (Rodríguez, 1998). In this respect, different authors have concluded that one of the key factors in achieving products with acceptable characteristics is maintaining the same moisture in nonfat substance (**MNFS**) ratio as found in full-fat cheese (Broadbent et al., 2001; Mistry, 2001). Several approaches have been investigated to increase the MNFS, and thus improve the texture of the low-fat cheeses (Broadbent et al., 2001; Mistry, 2001; Kondyli et al., 2002; Romeih et al., 2002). One of these approaches is adding fat replacer to the milk. Water-dispersible fat replacers, which consist mainly of microparticulated protein- or carbohydrate-based materials, have often been recommended for use in cheese products (Romeih et al., 2002). These materials act mainly by mechanically entrapping water, giving products a sense of lubricity and creaminess (i.e., rheological matching); however, they cannot effectively replace the nonpolar functional properties of fat, such as its flavor-carrying capacity. Billy (1981) was issued a patent for use of soy lecithin to increase the yield of full-fat cheeses. Volikakis et al. (2004) reported that the texture of a low-fat white-brined cheese improved by addition of oat-β-glucan concentrates. Koca and Metin (2004) investigated the textural, melting, and sensory properties of low-fat fresh Kashar cheeses produced with fat replacers. They found that the low-fat cheeses without fat replacer were significantly harder, more elastic, gummier, and more chewy and also had poorer

Received February 18, 2007.
Accepted May 15, 2007.
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meltability, appearance, texture, flavor, and overall acceptability scores than the full-fat cheeses. Mistry (2001) reported on the blending of microcrystalline cellulose, carrageenan, and NDM in cheese milk for Cheddar cheese of 11% fat. The cheese structure was softened by the interference of the CN-CN interaction from carrageenan and microcrystalline cellulose particles, which function similarly to fat globules by becoming embedded within the curd matrix. Mounsey and O'Riordan (2001) studied the effect of different native starches on the characteristics of imitation cheese and found reduced meltability and cohesiveness with an increasing starch concentration; hardness was increased by wheat, potato, and maize starches but reduced by waxy-maize or rice starches.

Iranian White cheese is a closely textured, brined cheese resembling Beyaz Peynir (Turkish White cheese) and Feta, although it differs from Feta in the way it is made. It is manufactured without dry-salting the curd and slime formation on the curd surface before brining, both of which are essential for the development of the characteristic Feta flavor during ripening (Fox, 1989). At the industrial level, the ripening period is 40 to 90 d, but cheeses made from raw milk in small rural production units may be ripened for 6 to 8 mo (Azarnia et al., 1997). Approximately 5,400 tons were produced annually between 2002 and 2006, and only by Pegah Dairy Co. factories (the largest group of dairy factories in Iran). Iranian White cheese is widely consumed throughout the country as a breakfast cheese and is used in the manufacture of other domestic cheese varieties, such as jug cheese.

In recent years, much attention has been given to the microstructure of cheese. Several techniques have been used for this purpose, for example, scanning electron microscopy (Ustunol et al., 1995; Drake et al., 1996; Madadlou et al., 2005, 2006, 2007; Khosrowshahi et al., 2006), confocal laser microscopy (Guinee et al., 1999; Mounsey and O'Riordan, 2001; Tunick, 2001), and transmission electron microscopy (Tunick, 2001; Pastorino et al., 2002). In particular, the use of scanning electron microscopy has become the method of choice in many investigations, and it has proved to be an efficacious method to identify cheese components when fat, protein, and moisture are the major constituents. The objective of this study was to evaluate the qualitative attributes of low-fat Iranian White cheese made with different concentrations of gum tragacanth during ripening. In this article, we report the changes in composition, color, and sensory properties of experimental samples as well as their full-fat and low-fat variants without addition of gum. We also used scanning electron microscopy and rheological experiments to investigate the effect of gum tragacanth on the textural properties of low-fat Iranian White cheese during ripening.

MATERIALS AND METHODS

Treatments, Cultures, Rennet, and Gum Tragacanth

Six treatments of cheese were made: 1) control full-fat cheese (**FFC**), 2) control low-fat cheese without gum tragacanth (**CLFC**), 3) low-fat cheese with 0.25 g of gum/kg of milk (**0.25 LFC**), 4) low-fat cheese with 0.5 g of gum/kg of milk (**0.5 LFC**), 5) low-fat cheese with 0.75 g of gum/kg of milk (**0.75 LFC**), and 6) low-fat cheese with 1 g of gum/kg of milk (**1 LFC**). Cheeses were manufactured in triplicate in 1 d, with each replicate using 6 kg of milk for each treatment. One lyophilized direct-to-vat mesophilic mixed culture (FRC-60, Chr. Hansen Dairy Cultures, Hørsholm, Denmark) containing *Lactococcus lactic* ssp. *cremoris*, *Lactococcus lactis* ssp. *lactis*, *Streptococcus thermophilus*, and *Lactobacillus delbrueckii* ssp. *bulgaricus* was used as starter at a ratio of 0.04 g/L of milk. As a coagulant, chymosin derived by fermentation [standard rennet, Chy-Max, Chr. Hansen; 183 international milk clotting units/mL (International Dairy Federation, 1997)] was used at a concentration of 4.5 international milk clotting units/kg of milk. Rennet was diluted 30-fold with cold water and then added to each 6-kg batch of milk. Gum tragacanth (KGaA 271, Merck, Darmstadt, Germany) was supplied by the Barnard Company (Urmia, Iran).

Cheese-Making Procedure

Raw skim milk (<0.25% fat) was standardized with cream of a determined fat content to 3% fat for the FFC and to 0.4% fat for low-fat cheeses. A 1-kg quantity of standardized milk (to 0.4% fat) was heated to 35°C, then supplemented with different levels of gum tragacanth and flash-pasteurized at 75°C for 15 s. The mixture were then transferred to a cheese vat (FT20-MKII cheese vat, Armfield Ltd., Ringwood, Hampshire, UK) and mixed with 5 kg of pasteurized milk of 0.4% fat. For complete mixing, agitation was gradually continued for 20 min. Milk was cooled to 35°C in this period and supplemented with 0.15 g of $CaCl_2$/kg of milk. The milk was held at 35°C for approximately 55 min after inoculation of the culture for starter activity before adding the rennet. The curd was cut crossways in cubes of 1.2 cm^3 when firm (after approximately 45 min). After being cut, the curd was allowed to settle for 3 to 5 min and then gently agitated at a gradually increasing rate for 10 min to avoid fusion of freshly cut curd cubes and to facilitate whey expulsion. This was followed by whey draining and pressing of the transferred curd into molds

(14 × 13 × 25 cm) for 2.5 h (under an initial pressure of 0.3 kPa, which was gradually increased up to approximately 2.9 kPa in the first hour and held constant until the end of pressing) to complete draining. After pressing, the curd was cut in blocks (4 × 6 × 6 cm). The blocks were stored at 23 to 25°C for 24 h, placed in airtight plastic containers, and covered with a 22% brine solution (the brine was pasteurized beforehand at 80°C for 10 min, and filtered through a clean cloth after rapid cooling). The containers were first stored at 23 to 25°C for 16 h, then the 22% brine solution was replaced by an 11% brine solution, and the containers were sealed and stored in a cold room at 5 to 6°C for the ripening period of 60 d. The FFC and CLFC were produced in a similar method, but without adding the gum tragacanth.

Chemical Analysis

Titrable acidity of the milk was determined by the Dohrnic method, and TS content was determined by drying 8 to 11 g of milk at 100°C for 5 h (Madadlou et al., 2006). The pH of milk and cheese samples was measured with a digital pH meter (microprocessor pH meter, model pH 537, WTW, Weinheim, Germany). Cheese was analyzed for moisture content by vacuum oven (AOAC, 1997). The fat content of milk and cheese samples was determined by the Gerber method (James, 1995) and their CP contents were determined by measuring total nitrogen by using the Kjeldahl method (AOAC, 1997) and converting it into protein content by multiplying by 6.38. All chemical measurements were done in triplicate or more. Cheese samples were chemically analyzed at d 3, 15, 30, 45, and 60 of ripening.

Cheese Yield, and Fat and Protein Recovery

Apparent yield was calculated as the weight of cheese before brining (after 24 h of storage at 23 to 25°C) divided by the weight of milk used. The percentage of fat or protein recovered in the cheese was the total amount of fat or protein in the cheese divided by the total amount of fat or protein in the milk (Johnson et al., 2001).

Ratio of Tyr-Trp Concentration to Protein Content

The proteolysis rate in 3-, 15-, 30-, 45-, and 60-d-old cheese slurries was measured by determining the Tyr-Trp concentrations in TCA extracts following the method of Khosrowshahi et al. (2006), divided by protein content (**T:P**). Cheese slurries were prepared by mixing 2 parts of the grated cheese sample with 1 part of a 5.2% sterile solution of sodium chloride at 45°C. Duplicate 1-g samples of slurries were each dispersed in 5.4 mL of distilled water and placed in a 40°C water bath for 5 min. Ten milliliters of a 12% (wt/vol) TCA solution was added to each suspension and allowed to stand for 10 min before being filtered through Whatman no. 2 filter paper. Five milliliters of each TCA extract was added to 10 mL of a solution containing 15% sodium carbonate and 2% sodium hexametaphosphate in Quickfit tubes kept in a 40°C water bath. This was followed by addition of 3 mL of 3× diluted Folin phenol reagent to the tubes. The contents were shaken thoroughly and then held in a 40°C water bath for 5 min before measuring the absorbance at 650 nm by a UV-visible spectrophotometer (ultrospect mode, model 80-2092-26, LKB Biochrom, Pharmacia, Cambridge, UK).

To 6 mL of distilled water was added 10 mL of 12% (wt/vol) TCA; the mixture was held at 40°C for 5 min and then filtered through Whatman no. 2 filter paper. The procedure was followed by addition of 5 mL of TCA filtrate and then 3 mL of Folin reagent to 10 mL of sodium hexametaphosphate solution. This solution was used as a blank. A Tyr standard curve was prepared by using concentrations of 0, 5, and 10 μg/mL in TCA filtrate, and up to 50 μg/mL.

Color Analysis

The color of 4-, 16-, 31-, and 61-d-old samples was quantitatively determined with a Hunter Lab system (model DP-9000, Hunter Associates Laboratory Inc., Reston, VA) in which the L-value corresponds to whiteness (Khosrowshahi et al., 2006). Color measurements were performed in triplicate for each treatment at different sites.

Rheological Analysis

Uniaxial Compression. The simplest fundamental test, uniaxial compression (Tunick, 2000), was performed at d 4, 16, 31, 46, and 61 of ripening with an HTE universal testing machine (S-Series Bench UTM model H5K-S, Hounsfield Test Equipment Ltd., Redhill, UK) with a 500-N load cell. A flat plunger with a 49-mm diameter was attached to the moving crosshead. Cheese blocks were cut into cylinders (24 mm diameter × 16 mm high) and immediately placed in airtight containers to prevent dehydration. Samples were equilibrated to room temperature (20 ± 1°C) for at least 4 h prior to testing. Samples were compressed uniaxially at a crosshead speed of 50 mm/min with 57% deformation (8.5 mm) from the initial head of the sample in one bite. The fracture stress (σf) was measured as the force divided by the initial cross-sectional area of the sample (Sipahioglu et al., 1999). The modulus of elasticity was

calculated as the secant modulus (Mohsenin, 1986) by using engineering strain at the fracture point. Each cheese was analyzed in triplicate.

Dynamic Rheological Measurements. Small-amplitude oscillatory shear measurements were performed with a UDS 200 rheometer (Universal Dynamic Spectrometer, Paar Physica Inc., Ashland, VA). The measuring geometry consisted of 2 parallel plates with a diameter of 25 mm and 1-mm gap size (sample thickness).

Samples of the cheese blocks were cut at least 1 cm deep at 6°C. These samples were immediately placed in small airtight plastic containers and equilibrated at room temperature (20 ± 1°C) for at least 4 h. Excess cheese was trimmed carefully with a razor blade, and the sample was allowed to rest for 20 min on the rheometer to allow the stress induced during sample handling to relax. Frequency was set at 10 Hz, because the strain values varied from 0.01 to 2.5%, resulting in a strain sweep. The parameters calculated were the storage modulus (**G′**) and the complex modulus (**G***), which are measures of elastic nature (Steff, 1996). Values are the average of 2 measurements for 3 replicates of each cheese. All rheological measurements were performed at d 4, 16, 31, 46, and 61 of ripening.

Microstructure

Cheese samples were prepared for scanning electron microscopy at d 4, 21, 35, and 49 of ripening following the method of Drake et al. (1996) with modifications. Cheese blocks were cut into approximately 5 to 6 mm^3 cubes with a sharp razor and immersed in 2.5% glutaraldehyde fixative (Merck) for 3 h. Cubes were then washed 6 times in distilled water (1 min each time), dehydrated in a graded (40, 55, 70, 85, 90, and 96%) series of ethanol for 30 min each, and defatted in 3 changes in chloroform (10 min each time). The defatted samples were kept refrigerated and covered with ethanol until they were freeze-fractured in liquid nitrogen (Sipahioglu et al., 1999) to approximately 1-mm pieces. These pieces were mounted on aluminum stubs by silver paint, dried to critical point, and coated with gold for 10 min in a sputter-coater (type SCD 005, Baltec Inc., Balzers, Switzerland). Samples were viewed in a scanning electron microscope (XL Series, model XL30, Philips, Eindhoven, the Netherlands) operated at 15.0 kV. Photomicrographs were recorded at 5,000× magnification.

Sensory Evaluation

An acceptance sensory panel evaluated randomly coded cheese samples. The acceptance (consumer) panel consisted of 64 members (36 males and 28 females) ranging in age from 23 to 33 yr. Consumer panelists were students from the School of Agricultural Engineering of Urmia University. Prior to testing, panelists were requested to complete a questionnaire asking their gender, age, and frequency of cheese consumption (do not eat cheese, 2 to 4 times/mo, 5 to 6 times/mo, and >6 times/mo). Panelists (n = 2) who consumed cheese 2 to 4 times/mo or less were eliminated from data analysis. The FFC, CLFC, 0.25 LFC, 0.5 LFC, 0.75 LFC, and 1 RFC cheeses were evaluated for texture, flavor, appearance, and overall acceptability by the consumer panel on a 5-point hedonic scale (1 = liked least, 5 = liked most). Cheese blocks were cut into standard, bite-sized pieces, with each piece measuring 1.3 × 0.9 × 0.9 cm (Madadlou et al., 2005). Cheese pieces were placed into airtight plastic containers and conditioned at room temperature for 2 h before evaluation. Crackers and water were offered to panelists without limit during testing to cleanse the palate. Sensory evaluation was done at 45 d of ripening.

Statistical Analysis

The experiments were replicated 3 times in a randomized complete block design, which incorporated the 6 treatments (FFC, CLFC, 0.25 LFC, 0.5 LFC, 0.75 LFC, and 1 LFC). An ANOVA was carried out by using the MSTATC statistical software package (Univ. Michigan) to determine the effects of treatment of all variables. Duncan's multiple comparisons test was used as a guide for pairwise comparisons of the treatment means. The level of significance was determined at $P < 0.05$.

RESULTS AND DISCUSSION

Milk Composition

Total chemical characteristics of the milk used for cheese manufacture are shown in Table 1. In agreement with the literature (Kahyaoglu and Kaya, 2003; Madadlou et al., 2005), as the fat content of the milk decreased, the moisture and protein contents increased significantly. There was no statistical difference in the pH value of the milks.

Composition of Cheese, Cheese Yield, and Protein and Fat Recovery

Table 2 shows the treatment composition, yield from cheese making, and T:P as an index of proteolysis in the curd. In agreement with the literature (Bryannt et al., 1995; Rudan et al., 1998a; McMahon et al., 1999; Dave et al., 2003; Kahyaoglu and Kaya, 2003; Madadlou et al., 2005), low-fat cheeses contained significantly

Table 1. Means ± SD of chemical characteristics of milks

Item	Full-fat milk	Low-fat milk
Fat, %	3.03 ± 0.12[a]	0.4 ± 0.01[b]
Moisture, %	89.48 ± 0.16[b]	91.46 ± 0.08[a]
Protein, %	3.17 ± 0.04[b]	3.26 ± 0.11[a]
pH	6.59 ± 0.02[a]	6.57 ± 0.02[a]
Acidity, °D	15.03 ± 0.17[a]	15.03 ± 0.16[a]

[a,b]Means within the same row with different superscripts differ ($P < 0.05$).

higher moisture and protein contents than did the FFC. Decreasing the fat content also led to a significant decrease in the level of MNFS and the ratio of moisture to protein (**M:P**), which was in agreement with the reports of other researchers (Rudan et al., 1998a; McMahon et al., 1999; Dave et al., 2003; Kahyaoglu and Kaya, 2003; Madadlou et al., 2005). The difference in moisture content between the FFC and the CLFC can be attributed to their protein content; that is, the higher protein content of reduced-fat cheeses may have contributed to an increased water-binding capacity of the cheese matrix (Romeih et al., 2002), leading to the increased moisture content. Fat and moisture act as fillers in the CN matrix of cheese texture. When the fat content was decreased, the moisture did not replace the fat on an equal basis (Rudan et al., 1998a), so the total filler volume was decreased, resulting in lower MNFS and M:P.

As the gum concentration increased, the percentage of protein decreased significantly; this occurred because of an increase in moisture content caused by the hydrophilic properties of the gum tragacanth and a decrease in syneresis. This result was in accordance with the report of Koca and Metin (2004), who also used a fat replacer. It has been suggested that water can bind directly to the fat replacer and that the fat replacer can interfere with the shrinkage of the CN matrix (Koca and Metin, 2004), which lowers the driving force involved in expelling water from curd particles (Madadlou et al., 2007). One of the most important strategies for improving the properties of low-fat cheese is to increase its moisture content sufficiently to provide an M:P or MNFS in the low-fat cheese that is equal to or greater than its full-fat counterpart (Broadbent et al., 2001). The moisture content and the MNFS of low-fat cheeses with gum tragacanth were significantly higher than those of the CLFC, whereas the protein content was significantly lower ($P < 0.05$).

The moisture content of cheeses (full-fat and low-fat cheeses) increased during ripening. The increased moisture content of cheese samples during ripening might show proteolysis, possibly because of adventitious microflora (Kaya, 2002). A large portion of the rennet is lost in the whey during cheese making (Madadlou et al., 2005), and in general, only about 6% of the rennet added to cheese milk is retained in the curd (Fox, 1989). The ratio of residual rennet to CN is higher in high-moisture cheeses than low-moisture cheeses (Zalazar et al., 2002), and the rate of proteolysis will therefore be higher. As shown Table 2, the protein content of all treatments decreased during ripening. Khosrowshahi et al. (2006) hypothesized that the decrease in protein content of Iranian White cheese during ripening could be due to the proteolysis and subsequent diffusion of free AA into the surrounding brine. Ehsani et al. (1999) reported that total nitrogen and NPN increased in brine during Iranian White cheese ripening. The increased moisture content during ripening and, as a result, the decrease in the protein fraction could be another reason for this. The increase in moisture content was lower in the final days of ripening and it changed very little. In agreement with the literature (Mistry and Kasperson, 1998; Rudan et al., 1998a; Fenelon et al., 1999; Kavas et al., 2004; Madadlou et al., 2005), the increased moisture content of low-fat cheeses induced a decrease in the fat content, leading to decreased fat in DM. Fat in DM decreased during ripening, which is in agreement with the report of Kavas et al. (2004), although the rate of this decrease was lower at the end of ripening. The MNFS in FFC was higher than in CLFC. Because the MNFS in cheese is related to milk fat (Ryhänen et al., 2001), the reduced fat in milk (and thus in cheese) reduced the MNFS. Supplementation of the low-fat milk used in cheese making with gum tragacanth increased the amount of MNFS in LFC to a point greater than that in FFC. The greater the amount of gum supplemented, the greater was the MNFS. This could be due to the greater water-binding capacity of gum. The M:P and MNFS in all treatments increased during ripening because of the increased moisture content and decreased protein content, although the rate of increase was lower at the end of ripening; in some cases, there was not a statistically ($P < 0.05$) significant difference between 2 subsequent periods.

Fat and protein recoveries in the cheese were also significantly affected by the fat content. Rudan et al. (1999) reported that the fat content significantly affected the percentage of fat recovery, but not the percentage of nitrogen recovery in Mozzarella cheese and whey. In the present study, as the target fat content in the cheese decreased, fat recovery significantly increased whereas protein recovery decreased. This result was in agreement with the findings of Madadlou et al. (2006) for Iranian White cheese. Supplementation of low-fat milk with gum tragacanth decreased fat recovery. The greater the gum concentration, the lower was

Table 2. Means ± SD of chemical composition, proteolyses rate, fat and protein recovery, and cheese yield during ripening

Sample[1]	Item[2]	Age, d 1	15	30	45	60
FFC	Moisture	52.56 ± 0.16^{p}	54.66 ± 0.72^{p}	56.54 ± 0.40^{o}	56.81 ± 0.54^{no}	57.70 ± 0.23^{mn}
	Fat	20.74 ± 0.26^{a}	18.82 ± 0.26^{b}	17.81 ± 0.27^{c}	17.38 ± 0.18^{d}	16.54 ± 0.24^{e}
	Protein	21.69 ± 0.28^{f}	20.57 ± 0.38^{hi}	18.72 ± 0.3^{j}	17.68 ± 0.10^{kl}	16.69 ± 0.08^{mn}
	M:P	2.43 ± 0.05^{p}	2.66 ± 0.05^{no}	3.02 ± 0.06^{lm}	3.21 ± 0.02^{jk}	3.46 ± 0.03^{hi}
	FDM	43.73 ± 0.54^{a}	41.51 ± 0.49^{b}	40.91 ± 0.65^{bc}	40.24 ± 0.4^{c}	39.11 ± 0.6^{d}
	Protein recovery	85.00 ± 4.42^{a}	—	—	—	—
	Fat recovery	85.03 ± 4.55^{b}	—	—	—	—
	MNFS	66.32 ± 0.27^{jk}	67.34 ± 0.32^{j}	68.68 ± 0.57^{i}	68.75 ± 0.57^{i}	69.14 ± 0.34^{h}
	pH	5.3 ± 0.01^{a}	5.25 ± 0.01^{ab}	5.17 ± 0.01^{cde}	5.12 ± 0.01^{efg}	5.05 ± 0.01^{hi}
	Yield	12.4 ± 0.37^{a}	—	—	—	—
	T:P	0.095 ± 0.04^{qr}	0.150 ± 0.06^{nopqr}	0.183 ± 0.07^{lmno}	0.390 ± 0.06^{g}	0.420 ± 0.06^{g}
CLFC	Moisture	58.49 ± 0.94^{m}	61.19 ± 0.14^{l}	62.14 ± 0.25^{kl}	62.67 ± 0.2^{k}	63.27 ± 0.23^{k}
	Fat	5.27 ± 0.04^{f}	4.65 ± 0.07^{g}	4.18 ± 0.09^{h}	3.78 ± 0.09^{i}	3.54 ± 0.09^{i}
	Protein	29.07 ± 0.55^{a}	26.99 ± 0.04^{b}	25.99 ± 0.07^{c}	24.66 ± 0.25^{d}	23.36 ± 0.13^{e}
	M:P	2.05 ± 0.05^{r}	2.27 ± 0.01^{q}	2.39 ± 0.02^{pq}	2.54 ± 0.03^{op}	2.71 ± 0.02^{n}
	FDM	13.00 ± 0.04^{e}	11.97 ± 0.15^{f}	11.03 ± 0.24^{g}	10.11 ± 0.2^{hi}	9.65 ± 0.27^{ig}
	Protein recovery	63.19 ± 0.1^{b}	—	—	—	—
	Fat recovery	91.91 ± 1.59^{a}	—	—	—	—
	MNFS	61.74 ± 0.5^{n}	64.17 ± 0.1^{m}	65.14 ± 0.26^{lm}	65.14 ± 0.06^{klm}	65.60 ± 0.27^{kl}
	pH	5.21 ± 0.01^{cd}	5.18 ± 0.01^{cd}	5.14 ± 0.01^{lm}	5.07 ± 0.01^{ghi}	4.99 ± 0.01^{jk}
	Yield	7.09 ± 0.1^{e}	—	—	—	—
	T:P	0.093 ± 0.04^{r}	0.164 ± 0.05^{mnop}	0.221 ± 0.05^{jklm}	0.482 ± 0.06^{f}	0.525 ± 0.05^{ef}
0.25 LFC	Moisture	64.42 ± 0.76^{j}	64.44 ± 0.25^{l}	67.62 ± 0.25^{kl}	68.03 ± 0.08^{h}	68.48 ± 0.03^{gh}
	Fat	3.72 ± 0.06^{i}	3.28 ± 0.04^{j}	2.88 ± 0.09^{k}	2.32 ± 0.05^{mn}	2.31 ± 0.01^{mn}
	Protein	24.15 ± 0.14^{d}	22.86 ± 0.27^{e}	21.32 ± 0.15^{fg}	20.25 ± 0.09^{h}	19.05 ± 0.37^{j}
	M:P	2.66 ± 0.03^{no}	2.91 ± 0.04^{m}	3.17 ± 0.02^{kl}	3.36 ± 0.01^{ij}	3.60 ± 0.07^{gh}
	FDM	10.65 ± 0.83^{gh}	9.77 ± 0.18^{i}	8.9 ± 0.37^{k}	7.25 ± 0.18^{m}	7.34 ± 0.04^{m}
	Protein recovery	59.11 ± 1.05^{b}	—	—	—	—
	Fat recovery	73.49 ± 1.48^{c}	—	—	—	—
	MNFS	66.9 ± 0.76^{j}	68.7 ± 0.28^{i}	69.02 ± 0.62^{hi}	69.64 ± 0.11^{ghi}	70.10 ± 0.03^{gh}
	pH	5.19 ± 0.01^{cd}	5.14 ± 0.01^{def}	5.08 ± 0.01^{gh}	5.02 ± 0.01^{ij}	4.93 ± 0.01^{klm}
	Yield	7.94 ± 0.1^{d}	—	—	—	—
	T:P	0.121 ± 0.04^{pqr}	0.186 ± 0.05^{lmno}	0.254 ± 0.05^{ijk}	0.506 ± 0.04^{f}	0.599 ± 0.06^{cd}
0.5 LFC	Moisture	67.72 ± 0.27^{h}	69.5 ± 0.07^{g}	72.69 ± 0.31^{de}	73.24 ± 0.62^{cd}	73.56 ± 0.68^{bde}
	Fat	3.21 ± 0.02^{j}	2.71 ± 0.03^{kl}	2.33 ± 0.06^{mn}	1.95 ± 0.03^{mn}	1.85 ± 0.03^{pq}
	Protein	21.8 ± 0.26^{f}	20.82 ± 0.29^{gh}	18.00 ± 0.28^{k}	17.17 ± 0.09^{lm}	16.08 ± 0.1^{no}
	M:P	3.11 ± 0.05^{kl}	3.34 ± 0.05^{ij}	4.04 ± 0.08^{f}	4.27 ± 0.05^{e}	4.57 ± 0.19^{d}
	FDM	10.09 ± 0.18^{hi}	8.9 ± 0.07^{k}	8.52 ± 0.28^{k}	6.97 ± 0.26^{mn}	4.57 ± 0.19^{d}
	Protein recovery	60.67 ± 1.07^{b}	—	—	—	—
	Fat recovery	70.08 ± 1.96^{cd}	—	—	—	—
	MNFS	69.84 ± 0.34^{ghi}	71.44 ± 0.06^{ef}	74.42 ± 0.34^{cd}	74.7 ± 0.62^{bc}	74.95 ± 0.69^{bc}
	pH	5.15 ± 0.01^{cde}	5.09 ± 0.01^{fgh}	5.03 ± 0.01^{hij}	4.98 ± 0.01^{jk}	4.88 ± 0.01^{mn}
	Yield	8.82 ± 0.12^{c}	—	—	—	—
	T:P	0.134 ± 0.04^{opqr}	0.203 ± 0.04^{klmn}	0.276 ± 0.04^{de}	0.561 ± 0.04^{de}	0.646 ± 0.05^{bc}
0.75 LFC	Moisture	68.83 ± 0.52^{gh}	71.78 ± 0.09^{ef}	73.61 ± 0.22^{bcd}	73.97 ± 0.03^{bc}	74.43 ± 0.38^{abc}
	Fat	2.81 ± 0.01^{k}	2.18 ± 0.02^{no}	1.96 ± 0.03^{op}	1.67 ± 0.03^{qr}	1.51 ± 0.01^{rs}
	Protein	20.04 ± 0.18^{i}	18.68 ± 0.02^{j}	16.99 ± 0.08^{lm}	15.58 ± 0.29^{o}	14.47 ± 0.17^{p}
	M:P	3.43 ± 0.01^{i}	3.94 ± 0.1^{f}	4.33 ± 0.01^{f}	4.75 ± 0.01^{c}	1.15 ± 0.06^{b}
	FDM	9.02 ± 0.07^{jk}	7.73 ± 0.05^{lm}	7.42 ± 0.3^{m}	6.40 ± 0.16^{no}	5.90 ± 0.06^{o}
	Protein recovery	60.34 ± 1.6^{b}	—	—	—	—
	Fat recovery	68.36 ± 1.39^{cd}	—	—	—	—
	MNFS	70.82 ± 0.54^{fh}	73.38 ± 0.09^{p}	75.08 ± 0.24^{bc}	75.22 ± 0.03^{abc}	75.57 ± 0.38^{no}
	pH	5.04 ± 0.01^{jk}	4.95 ± 0.01^{kl}	4.92 ± 0.01^{lmn}	4.86 ± 0.01^{n}	4.80 ± 0.01^{o}
	Yield	9.82 ± 0.15^{b}	—	—	—	—
	T:P	0.143 ± 0.04^{opqr}	0.217 ± 0.04^{klm}	0.194 ± 0.04^{hi}	0.600 ± 0.05^{cd}	0.693 ± 0.05^{b}
1 LFC	Moisture	70.65 ± 0.6^{f}	73.58 ± 0.13^{bcd}	74.51 ± 0.3^{abc}	74.67 ± 0.6^{ab}	75.36 ± 0.35^{a}
	Fat	2.5 ± 0.03^{lm}	1.88 ± 0.03^{pq}	1.57 ± 0.02^{rs}	1.48 ± 0.02^{rs}	1.40 ± 0.01^{s}
	Protein	19.3 ± 0.12^{j}	17.56 ± 0.13^{kl}	16.29 ± 0.19^{n}	14.81 ± 0.26^{p}	13.62 ± 0.30^{q}
	M:P	3.73 ± 0.08^{g}	4.19 ± 0.04^{e}	4.58 ± 0.06^{d}	5.05 ± 0.1^{b}	5.47 ± 0.09^{a}
	FDM	8.41 ± 0.12^{kl}	7.08 ± 0.07^{mn}	5.96 ± 0.07^{o}	5.84 ± 0.02^{o}	5.68 ± 0.06^{o}
	Protein recovery	61.12 ± 1.25^{b}	—	—	—	—
	Fat recovery	63.92 ± 1.93^{e}	—	—	—	—
	MNFS	72.12 ± 0.29^{e}	74.99 ± 0.12^{bc}	57.7 ± 0.29^{abc}	75.78 ± 0.35^{ab}	76.43 ± 0.35^{a}
	pH	4.98 ± 0.01^{jk}	4.92 ± 0.01^{lmn}	4.87 ± 0.01^{n}	4.79 ± 0.01^{op}	4.74 ± 0.01^{p}
	Yield	10.32 ± 0.15^{b}	—	—	—	—
	T:P	0.152 ± 0.04^{nopq}	0.231 ± 0.04^{nopq}	0.316 ± 0.04^{h}	0.649 ± 0.4^{bc}	0.750 ± 0.06^{i}

$^{a–s}$Means within the same row with different superscripts differ ($P < 0.05$).

[1]FFC = full-fat control cheese; CLFC = control low-fat cheese without gum tragacanth; 0.25 LFC = low-fat cheese with 0.25 g of gum/kg of milk; 0.5 LFC = low-fat cheese with 0.5 g of gum/kg of milk; 0.75 LFC = low-fat cheese with 0.75 g of gum/kg of milk; 1 LFC = low-fat cheese with 1 g of gum/kg of milk.

[2]M:P = ratio of moisture to protein; FDM = fat in DM; MNFS = moisture in nonfat substances; T:P = ratio of Tyr-Trp concentration to protein content, as the proteolysis rate.

the fat recovery, although protein recovery was similar among the different low-fat cheeses. The cheese-making yield decreased significantly as the fat content in cheese decreased. Milk fat, one of the major components in milk, is trapped in the CN matrix during cheese making (Rudan et al., 1999). Although it is true that fat in cheese is replaced by moisture (Mistry, 2001), an overall reduction in yield (kilograms of cheese per kilogram of milk) is inevitable in the production of cheese from low-fat milk (Romeih et al., 2002) because the total amount of fat removed is not equal to the amount of moisture added (Mistry, 2001). Therefore, the sum of the CN and fat contents of the milk, which are the principal components determining cheese yield, are reduced (Romeih et al., 2002). As the gum concentration increased, the cheese yield significantly increased because of the water-binding property of the gum and the increasing moisture content, although there was no significant difference between 0.75 LFC and 1 LFC.

The reduction in fat and the increase in gum concentration significantly decreased the pH of the product. The pH of cheeses decreased during ripening, which was in agreement with the findings of Azarnia et al. (1997).

As shown in Table 2, T:P increased in CLFC compared with FFC. This was due to the higher soluble chymosin (Rudan et al., 1998b), as well as the enhanced activity and growth of microorganisms (Mistry, 2001). In addition, when the gum concentration increased, the ratio of proteolysis was increased, which was probably due to the increased moisture content. This finding is in agreement with the results of Madadlou et al. (2005) for Iranian White cheese. The T:P in cured cheese increased during ripening. This was in agreement with reports in the literature (Romeih et al., 2002; Michaelidou et al., 2003a; Prieto et al., 2004; Volikakis et al., 2004; Khosrowshahi et al., 2006).

Cheese Opacity

The L-values of treatments after 4, 16, 31, 45, and 61 d of storage are shown in Figure 1. The scattering of light by any system is related to its heterogeneity (Madadlou et al., 2006) at the microstructural levels (Rudan et al., 1998b). In a solid material such as cheese, light penetrates the superficial layers and is scattered by milk fat globules (Lemay et al., 1994) and the edges of whey pockets (Paulson et al., 1998). The L-value describes the whiteness of the cheese samples. The FFC had a lower whiteness in comparison with LFC. In addition, the supplementation of low-fat milk with gum tragacanth resulted in a marked increase in whiteness. A higher gum concentration increased the moisture content and the M:P (Table 2), leading to an increased surface area occupied by scattering centers. As ripening progressed, the whiteness of all cheese samples decreased. The decrease in whiteness during storage is probably associated with increased protein hydration, which reflects a decrease in the number of free moisture droplets and thus a reduced degree of light scattering (Sheehan et al., 2005). Khosrowshahi et al. (2006) also reported that whiteness decreased in Iranian White cheese during ripening. The current findings are in agreement with the literature (Rudan et al., 1998b; Sheehan et al., 2005).

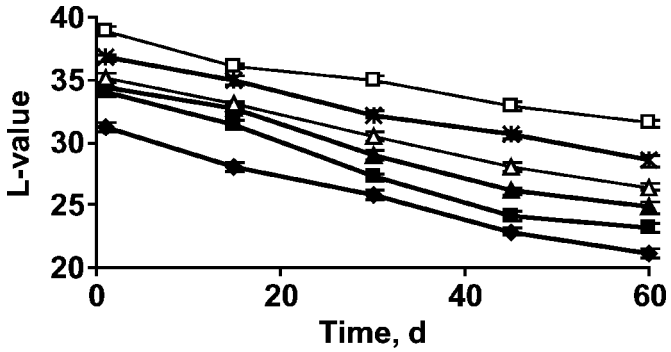

Figure 1. Whiteness (L-value) of cheese samples during ripening. Full-fat control cheese (–◆–); control low-fat cheese without gum tragacanth (–■–); low-fat cheese with 0.25 g of gum/kg of milk (–▲–); low-fat cheese with 0.5 g of gum/kg of milk (–△–); low-fat cheese with 0.75 g of gum/kg of milk (–*–); low-fat cheese with 1 g of gum/kg of milk (–□–).

Rheological Analysis

Uniaxial Compression. The uniaxial compression parameters of the treatments are shown in Figures 2 and 3. The fracture stress and modulus of elasticity are related to cheese softness (Madsen and Ardö, 1995; Ustunol et al., 1995); that is, a greater fracture stress and modulus of elasticity indicate a cheese with a firmer and more elastic texture. The CLFC had a higher fracture stress and modulus of elasticity than the FFC. Madadlou et al. (2005) also reported similar results for a low-fat Iranian White cheese. An increase in the concentration of gum tragacanth induced a significant decrease in these 2 parameters, so in the 1 LFC the fracture stress and modulus of elasticity were close to those of the FFC. These 2 parameters decreased during ripening as well. Fat and moisture act as fillers in the CN matrix of cheese (Madadlou et al., 2005), giving it lubricity and softness, whereas the CN matrix provides cheese texture with an elastic character. The decrease in the volume of the force-bearing component (protein) of the cheese microstructure during ripening (Table 2) could account for most of the reduced firmness.

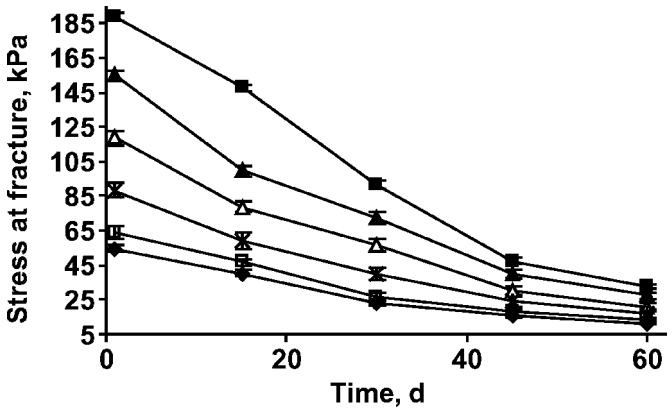

Figure 2. Fracture stress of Iranian White cheeses during ripening. Full-fat control cheese (–◆–); control low-fat cheese without gum tragacanth (–■–); low-fat cheese with 0.25 g of gum/kg of milk (–▲–); low-fat cheese with 0.5 g of gum/kg of milk (–△–); low-fat cheese with 0.75 g of gum/kg of milk (–*–); low-fat cheese with 1 g of gum/kg of milk (–□–).

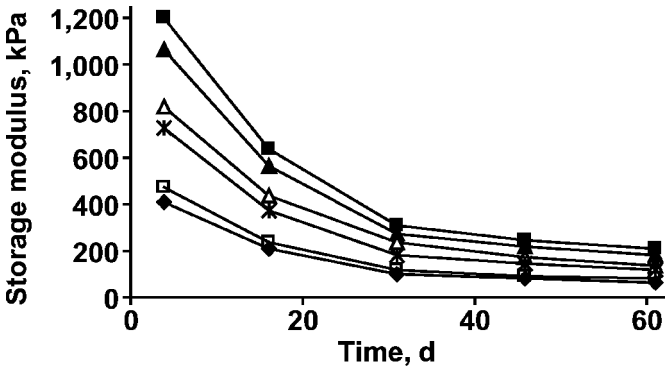

Figure 4. Storage moduli of Iranian White cheeses during ripening. Full-fat control cheese (–◆–); control low-fat cheese without gum tragacanth (–■–); low-fat cheese with 0.25 g of gum/kg of milk (–▲–); low-fat cheese with 0.5 g of gum/kg of milk (–△–); low-fat cheese with 0.75 g of gum/kg of milk (–*–); low-fat cheese with 1 g of gum/kg of milk (–□–).

In the model of Horne (1998), micellar calcium phosphate is not regarded as merely a cross-link between CN nanoclusters, but also as a neutralizing agent, which, being positively charged, binds to negatively charged phosphoserine clusters. This reduces the protein charge to the point at which the attractive interactions between hydrophobic regions of the CN can be allowed to dominate. During ripening and by increasing the gum tragacanth concentration, pH decreased (Table 2), which induced the dissolution out of colloidal calcium phosphate (Khosrowshahi et al., 2006). However, the micelle does not dissociate at temperatures higher than 25°C (Banon and Hardy, 1992) by the dissolution of colloidal calcium phosphate when pH is decreased (Dalgleish and Law, 1989; Lucey et al., 2003). This is due to the concurrent neutralization of the phosphoserine charge by the acid (Horne, 1998). The reduction in the amount of calcium associated with CN molecules would, however, increase the electrostatic repulsion between CN particles (Lucey et al., 2003) and cause a weakening of the structural bonds (Horne, 1998). This probably contributed to the decrease in fracture stress with the increase in gum tragacanth concentration as ripening progressed. This finding is in agreement with Khosrowshahi et al. (2006), who reported that the fracture stress of Iranian White cheese decreased during ripening.

Dynamic Rheological Measurements. The dynamic rheological parameters of treatments are shown in Figures 4 and 5. The strain-sweep test was used

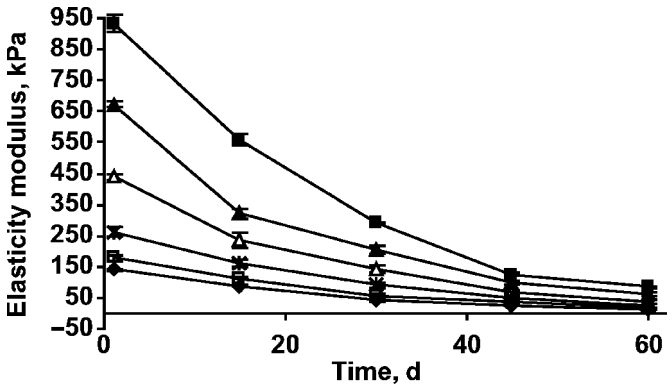

Figure 3. Elasticity moduli of Iranian White cheeses during ripening. Full-fat control cheese (–◆–); control low-fat cheese without gum tragacanth (–■–); low-fat cheese with 0.25 g of gum/kg of milk (–▲–); low-fat cheese with 0.5 g of gum/kg of milk (–△–); low-fat cheese with 0.75 g of gum/kg of milk (–*–); low-fat cheese with 1 g of gum/kg of milk (–□–).

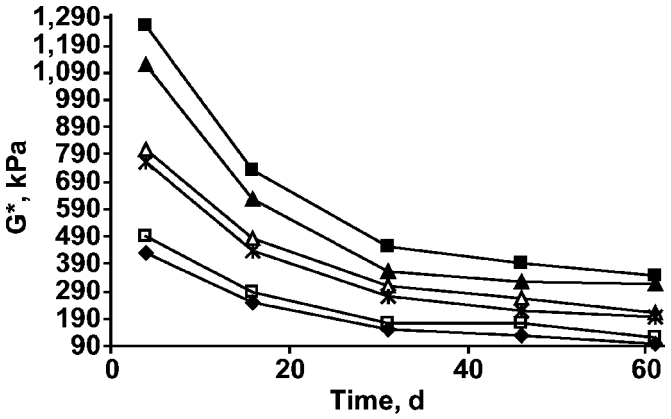

Figure 5. Complex moduli (G*) of Iranian White cheeses during ripening. Full-fat control cheese (–◆–); control low-fat cheese without gum tragacanth (–■–); low-fat cheese with 0.25 g of gum/kg of milk (–▲–); low-fat cheese with 0.5 g of gum/kg of milk (–△–); low-fat cheese with 0.75 g of gum/kg of milk (–*–); low-fat cheese with 1 g of gum/kg of milk (–□–).

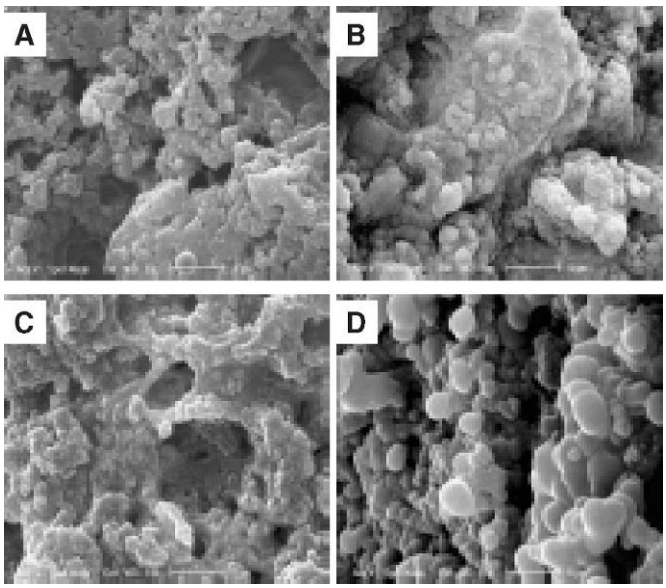

Figure 6. Microstructure of full-fat cheese (FFC) during ripening at d 4, (A), 21 (B), 35 (C), and 49 (D).

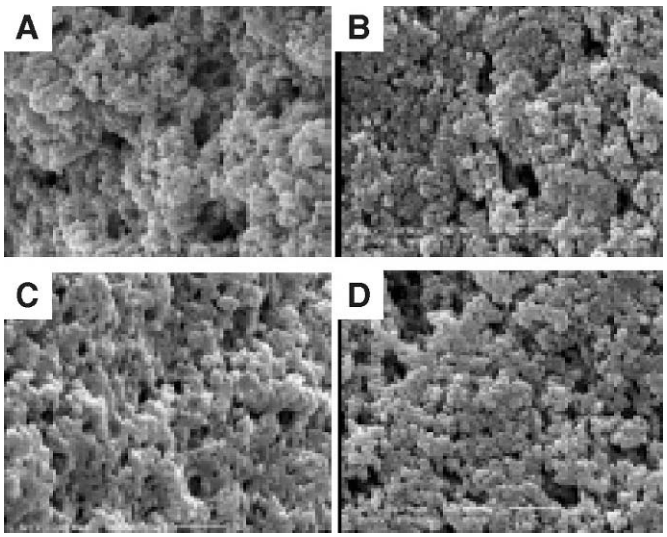

Figure 8. Microstructure of low-fat cheese with 0.25 g of gum/kg of milk (0.25 LFC) during ripening at d 4 (A), 21 (B), 35 (C), and 49 (D).

to determine whether fat reduction progressed during ripening and whether a reduction in gum tragacanth influenced the textural characteristics of the cheese. The lower G′ for FFC indicated a lower elastic contribution as a consequence of the higher fat and lower moisture contents in this cheese (Table 2; Zalazar et al., 2002). Similar to fracture stress, the G′ is related to cheese softness (Madadlou et al., 2005). The magnitude of fracture stress and G′ values depends on the number and strength of bonds between CN particles and on the structure and spatial distribution of strands of CN in the gel network (Madadlou et al., 2006). The reduction in fat content in this study significantly increased the values of G′ and G*, probably because of the increased proportion of the protein fraction (Table 2). Decreased MNFS and M:P in the CLFC led to the higher moduli than in the FFC. Although the results obtained in the present study were not similar to those found by Ma et al. (1996), who reported that full-fat Cheddar cheese had a more solid-like structure, similar results have been reported frequently by other researchers (Dave et

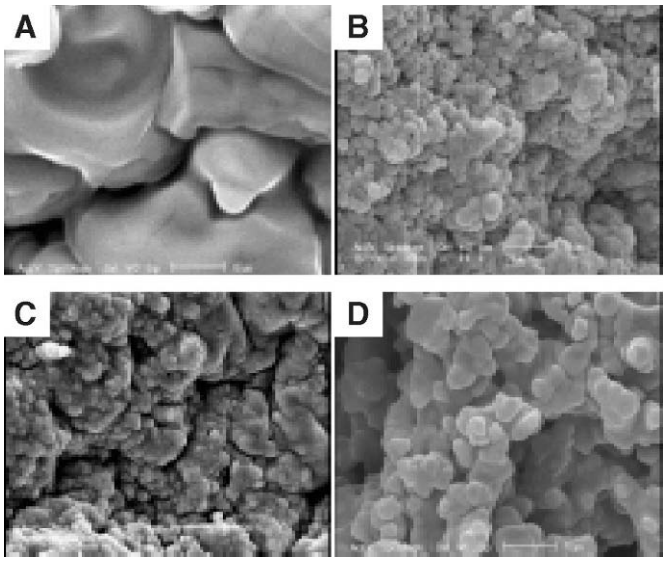

Figure 7. Microstructure of control low-fat cheese (CLFC) during ripening at d 4, (A), 21 (B), 35 (C), and 49 (D).

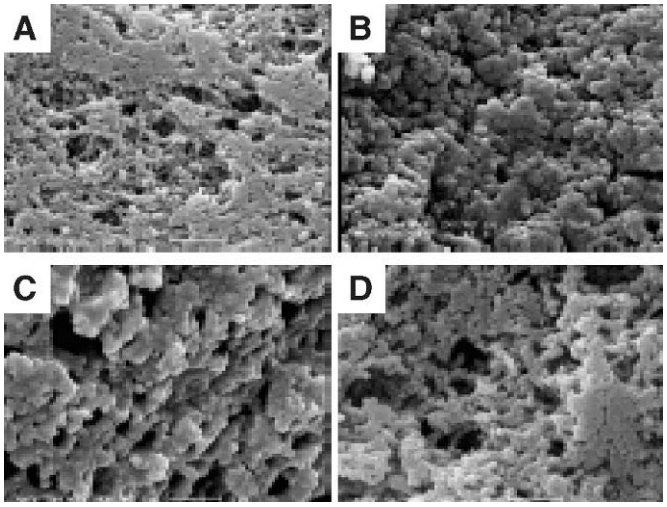

Figure 9. Microstructure of low-fat cheese with 0.5 g of gum/kg of milk (0.5 LFC) during ripening (at d 4, (A), 21 (B), 35 (C), and 49 (D)).

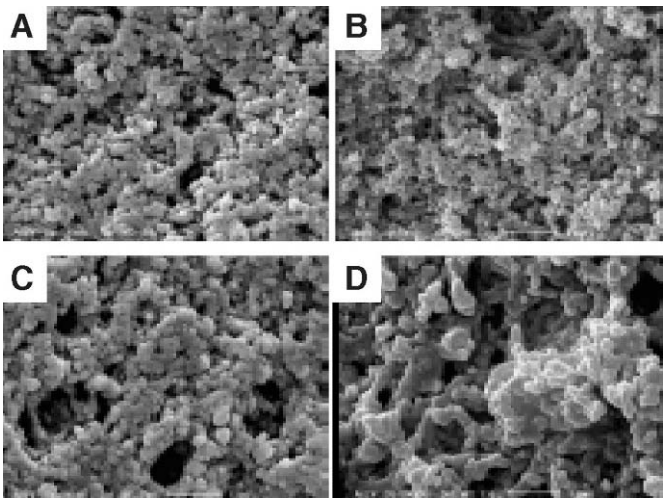

Figure 10. Microstructure of low-fat cheese with 0.75 g of gum/kg of milk (0.75 LFC) during ripening at d 4 (A), 21 (B), 35 (C), and 49 (D).

al., 2003; Kahyaoglu and Kaya, 2003; Madadlou et al., 2005). An increased concentration of gum tragacanth decreased G′ and G*, whereas according to the findings of Zalazar et al. (2002), the rheological behavior of low-fat cheeses was not affected by the addition of a fat replacer.

The G′ and G* values decreased during ripening. The ratio of residual rennet to CN is higher in high-moisture cheeses than in low-moisture cheeses, and the rate of softening in texture will therefore be higher (Zalazar et al., 2002). Consequently, it was not surprising that the high-moisture cheeses manufactured in this study were semiliquid after 30 d of ripening.

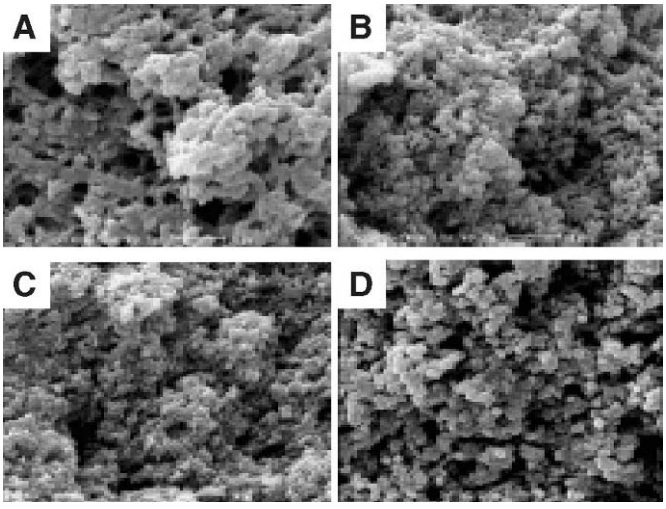

Figure 11. Microstructure of low-fat cheese with 1 g of gum/kg of milk (1 LFC) during ripening at d 4 (A), 21 (B), 35 (C), and 49 (D).

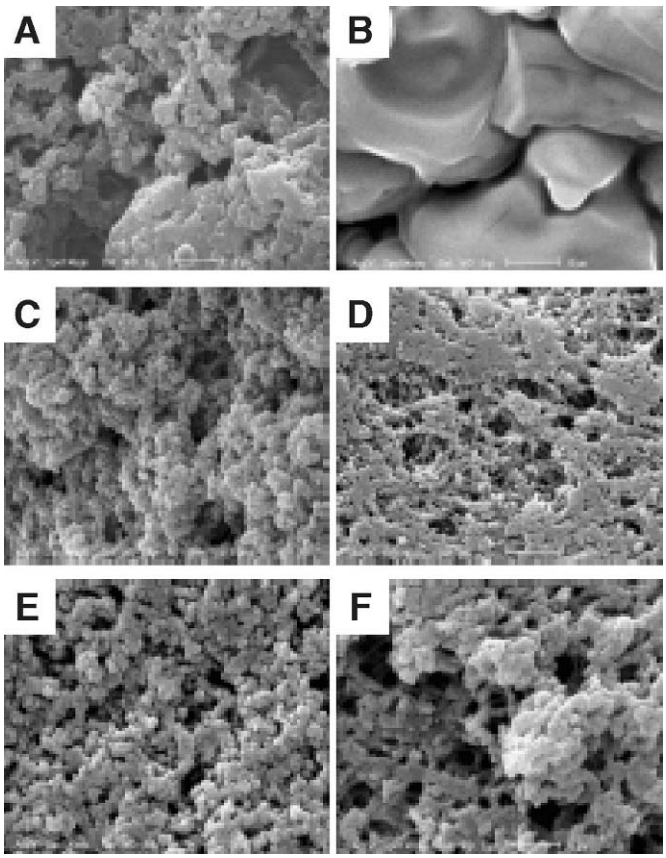

Figure 12. Microstructure of cheese samples at d 4: full-fat control cheese (FFC; A), control low-fat cheese without gum tragacanth (CLFC; B), low-fat cheese with 0.25 g of gum/kg of milk (0.25 LFC; C), low-fat cheese with 0.5 g of gum/kg of milk (0.5 LFC; D), low-fat cheese with 0.75 g of gum/kg of milk (0.75 LFC; E), low-fat cheese with 1 g of gum/kg of milk (1 LFC; F).

Microstructure

Every cheese variety has its characteristic structural features, which reflect the biochemical changes in the cheese (Madadlou et al., 2005). Differences between cheeses could be visually observed in images obtained by scanning electron microscopy (Figures 6 to 15). In the scanning electron micrographs of the FFC, the protein matrix was open, with spaces occupied by the fat globules. The holes in the protein matrix indicate the spaces occupied by fat globules before extraction by chloroform (Metzger and Mistry, 1995). The microstructure of the CLFC was clearly different from that of the FFC, with the number of milk fat globules decreasing and the protein matrix becoming more compact. This probably explained the harder texture observed in the CLFC, even though it was significantly higher in moisture content (Bryannt et al., 1995), as shown in Table 2. In one period, for example, at d 4 (Figure 12), when the gum tragacanth concentration was increased, the protein

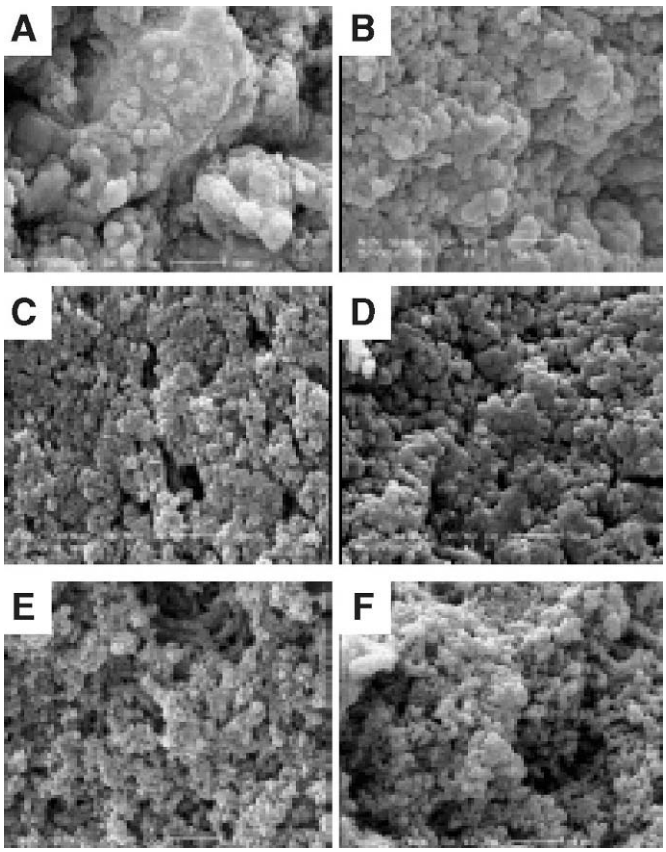

Figure 13. Microstructure of cheese samples at d 21: full-fat control cheese (FFC; A), control low-fat cheese without gum tragacanth (CLFC; B), low-fat cheese with 0.25 g of gum/kg of milk (0.25 LFC; C), low-fat cheese with 0.5 g of gum/kg of milk (0.5 LFC; D), low-fat cheese with 0.75 g of gum/kg of milk (0.75 LFC; E), low-fat cheese with 1 g of gum/kg of milk (1 LFC; F).

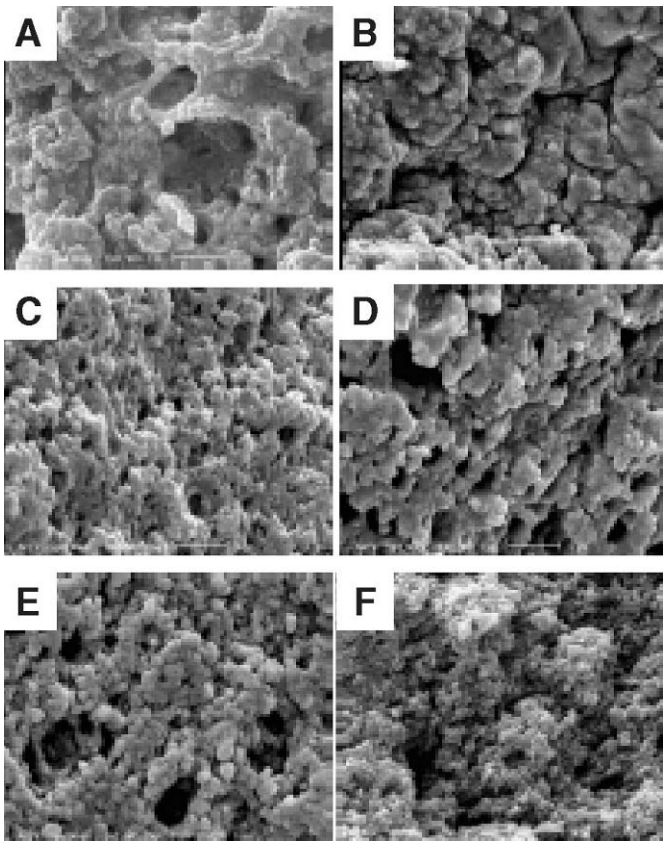

Figure 14. Microstructure of cheese samples at d 35: full-fat control cheese (FFC; A), control low-fat cheese without gum tragacanth (CLFC; B), low-fat cheese with 0.25 g of gum/kg of milk (0.25 LFC; C), low-fat cheese with 0.5 g of gum/kg of milk (0.5 LFC; D), low-fat cheese with 0.75 g of gum/kg of milk (0.75 LFC; E), low-fat cheese with 1 g of gum/kg of milk (1 LFC; F).

matrix became open. We concluded that it was opened with spaces occupied by the moisture. The higher the amount of gum, the higher was the moisture content (Table 2), so the matrix was more open. This happened in other periods of ripening as well (Figures 13 to 15) and probably explains the soft texture observed with the low-fat cheeses with a high amount of gum. Rheological measurements showed that the low-fat cheeses without gum and with a low amount of gum had higher elastic moduli and fracture stress than the low-fat cheeses with a high amount of gum (Figures 2 and 3). We propose that the network had become coarse, as we observed in the microstructure. The hydrolysis of the cheese protein network and subsequent diffusion of small peptides and free AA to the surrounding brine may account for the microstructural changes that were observed during ripening with the increased concentrations of gum tragacanth.

Sensory Evaluation

Table 3 shows the scores of taste panelists for cheese treatments at 45 d after storage. As expected, the FFC received the highest score for all attributes. The reduction in fat content significantly affected the texture, appearance, flavor, and overall acceptability of Iranian White cheese.

Madadlou et al. (2005) also reported that low-fat Iranian White cheeses received lower flavor and texture scores than full-fat cheese. Cheeses with lower fat usually have a less pronounced flavor than full-fat products, possibly as a result of flavor dilution in reduced- and low-fat cheeses because of excessive moisture retention (Sipahioglu et al., 1999). The fat in cheese carries much of the flavor (Madadlou et al., 2005), and when fat is decreased, the cheese flavor decreases. Supplementating the low-fat milk used in cheese making with gum tragacanth led to higher scores on the evaluated attributes. The 0.75 LFC received higher scores

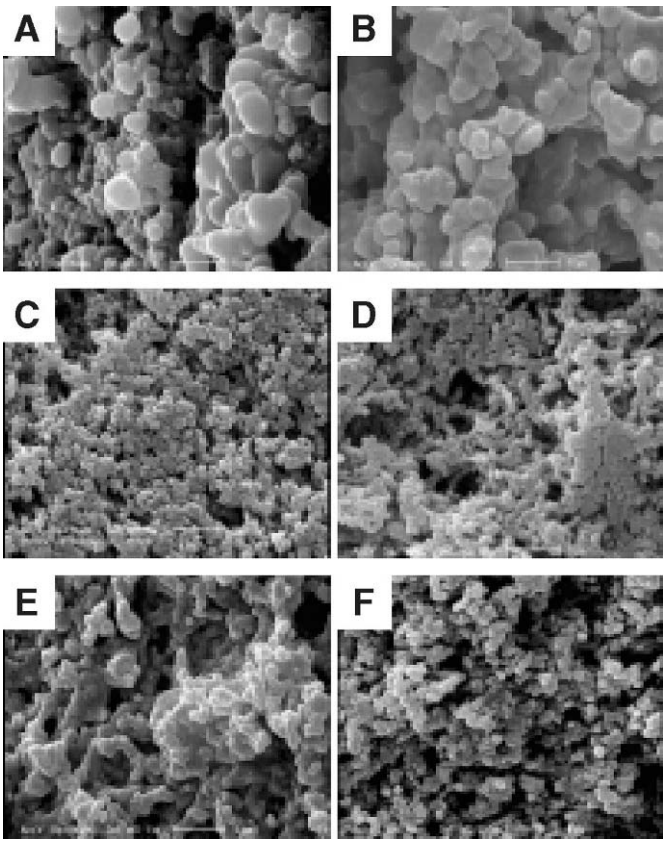

Figure 15. Microstructure of cheese samples at d 49: full-fat control cheese (FFC; A), control low-fat cheese without gum tragacanth (CLFC; B), low-fat cheese with 0.25 g of gum/kg of milk (0.25 LFC; C), low-fat cheese with 0.5 g of gum/kg of milk (0.5 LFC; D), low-fat cheese with 0.75 g of gum/kg of milk (0.75 LFC; E), low-fat cheese with 1 g of gum/kg of milk (1 LFC; F).

after the FFC for texture, appearance, and overall acceptability. However, the scores for 1 LFC were lower than those for 0.75 LFC. Our belief is that the very high moisture content in 1 LFC probably induced these unfavorable attributes in comparison with 0.75 LFC.

Table 3. Means ± SD of sensory attributes of FFC, CLFC, 0.25 LFC, 0.5 LFC, 0.75 LFC, and 1 LFC[1]

Item	Appearance	Texture	Flavor	Overall acceptance
FFC	4.32 ± 0.20[a]	4.27 ± 0.34[a]	4.19 ± 0.30[a]	4.17 ± 0.25[a]
CLFC	1 ± 0.13[d]	0.9 ± 0.15[d]	0.8 ± 0.15[c]	1.1 ± 0.17[d]
0.25 LFC	1.2 ± 0.15[d]	1.1 ± 0.18[d]	2.20 ± 0.18[b]	1.3 ± 0.15[d]
0.5 LFC	2.5 ± 0.21[c]	2.05 ± 0.20[c]	2.30 ± 0.21[b]	2.2 ± 0.20[c]
0.75 LFC	3.2 ± 0.24[b]	3.15 ± 0.25[b]	2.30 ± 0.24[b]	3.00 ± 0.26[b]
1 LFC	2.6 ± 0.22[c]	2.15 ± 0.23[c]	2.20 ± 0.24[b]	4.2 ± 0.23[c]

[a–d]Means within the same column with different superscripts differ ($P < 0.05$).

[1]FFC = full-fat control cheese; CLFC = control low-fat cheese without gum tragacanth; 0.25 LFC = low-fat cheese with 0.25 g of gum/kg of milk; 0.5 LFC = low-fat cheese with 0.5 g of gum/kg of milk; 0.75 LFC = low-fat cheese with 0.75 g of gum/kg of milk; 1 LFC = low-fat cheese with 1 g of gum/kg of milk.

CONCLUSIONS

This study indicated that the fat content, amount of gum tragacanth, and ripening time had major effects on the cheese-making yield, chemical characteristics, rheological characteristics, and microstructure of Iranian White cheese. As the fat content in cheese decreased, the instrumental hardness parameters increased and the microstructure became more compact. Adding gum tragacanth to the low-fat cheeses increased their moisture content and improved their sensory properties, but only to 0.75 g of gum/kg of milk. Gum tragacanth improved the rheological properties of texture, probably because of its water-binding ability. The instrumental hardness parameters decreased during ripening, and interactions with the gum tragacanth concentration caused visible undesirable effects on cheese characteristics after 42 d of ripening.

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