JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Rheological and Proteolytic Properties of Monterey Jack Goat's Milk Cheese during Aging

DIANE L. VAN HEKKEN,*,† MICHAEL H. TUNICK,† AND YOUNG W. PARK§

Dairy Processing and Products Research Unit, Eastern Regional Research Center, Agricultural Research Service, U.S. Department of Agriculture, 600 East Mermaid Lane, Wyndmoor, Pennsylvania 19038, and Georgia Small Ruminant Research and Extension Center, Fort Valley State University, 1005 State College Drive, Fort Valley, Georgia 31030-4313

To enhance the understanding of the quality traits of goat's milk cheeses, rheological and proteolytic properties of Monterey Jack goat's milk cheese were evaluated during 26 weeks of 4 °C storage. As expected with aging, β-casein levels decreased with concomitant increases in peptide levels and were correlated with changes in rheological properties of the cheese. Hydrolysis of the protein matrix resulted in more flexible (increased viscoelastic properties) and softer (decreased hardness, shear stress, and shear rigidity) cheeses. During the first 4−8 weeks of storage, cheese texture changed significantly ($P < 0.05$) and then stabilized. Characterization of rheological and proteolytic properties of the goat's milk semihard cheese during aging provided insight into the changes occurring in the protein matrix, the relationship to structure, and a shift in cheese quality.

KEYWORDS: Goat cheese; Monterey Jack; aging; rheology; proteolysis

INTRODUCTION

The manufacture of goat's milk cheese is a relatively small but growing industry in the United States with 1 million dairy goats producing 24000 tons of fluid milk a year; a portion of that milk goes to the manufacture of 600 tons of cheese (*1*). Although many milk producers are managing their herds to milk throughout the year, the industry is still challenged by seasonal milking practices that limit the availability of goat's milk from fall to spring. Future growth of the dairy goat industry depends on the production and successful marketing of high-quality cheeses that are available throughout the year.

One quality trait, texture, is closely related to the specific proteins in the cheese. The quantity and distribution of the caseins, as well as the manufacturing steps, determine the structure of the cheese matrix. Because of species differences, only a portion of the cheese research conducted on cow's milk cheeses can be directly applied to goat's milk counterparts. The caseins of goat's and cow's milk are similar in amino acid sequence and structure (with some minor genetic variations) and respond to proteolytic enzymes in similar manners (*2*−*5*), whereas the ratio of the caseins in the milks are not the same. Goat's milk contains an α_{s2}-:β-:κ-casein (CN) ratio of approximately 1:3:1. Depending on the genetics of the individual goat, α_{s1}-CN may or may not be present in low concentrations (*6*, *7*) and alters micelle conformation (*8*) and cheesemaking properties, such as coagulation rates, curd firmness, and yields (*2*, *6*, *7*). Proteolysis is essential for texture development in semihard and hard cheeses and has been tracked using SDS-PAGE for a number of goat's milk cheeses (*3*, *9*−*12*).

Cheese texture is quantified using rheological analyses that measure the response to either small or large deformations of the cheese (*13*). Small-amplitude oscillatory shear analysis (SAOSA) stretches internal bonds using small-strain oscillatory motion and measures the viscoelastic properties (elastic and viscous moduli, complex viscosity) of the curd. Texture profile analysis (TPA) mimics chewing through the use of large destructive shear, and the hardness, springiness, and cohesive nature of the cheese are calculated. Torsion analysis (TA) twists the sample until it fractures to obtain the shear stress, strain, and rigidity of the cheese. The hardness and fracturability of a Cheddar-like goat's milk cheese have been measured using TPA, but it was not related to proteolysis (*14*). Little information has been available on the texture of goat's milk cheese, especially the impact of proteolysis on the rheological properties.

The production of semihard and hard cheeses that require aging is one way to extend the availability of goat's milk products throughout the year. One semihard cheese of interest is Monterey Jack, a popular American-style specialty cheese with a firm body, smooth texture, good meltability, and mild flavor (*15*). Monterey Jack is made using a modified Cheddar cheese procedure (*17*), but it has a higher moisture content (up to 44% versus <39% moisture for Cheddar). Although several studies have been conducted on the proteolysis of aging goat's milk Monterey Jack cheeses (*10*, *12*, *16*), the rheological properties have not been reported. The objectives of the present study were (1) to characterize the effect of aging on the rheological properties of Monterey Jack goat's milk cheeses stored at 4 °C and (2) to study the relationship between

* Corresponding author [telephone (215) 836-3777; fax (215) 233-6795; e-mail dvanhekken@errc.ars.usda.gov].
† U.S. Department of Agriculture.
§ Fort Valley State University.

10.1021/jf049918q CCC: $27.50
Published on Web 07/28/2004

rheological and proteolytic changes in the cheeses during 26 weeks of aging.

MATERIALS AND METHODS

Goat Cheeses. Monterey Jack goat cheeses were manufactured using the bulk milk from a mixed herd of mid-lactation Nubian, Saanen, and Alpine goats from the Small Ruminant Research and Extension Center, Fort Valley State University, Fort Valley, GA. The milk was pasteurized at 63 °C for 30 min. Two batches of Monterey Jack cheese were manufactured on consecutive weeks in the University's dairy processing plant using a slightly modified version of the procedure described by Kosikowski and Mistry (*17*). Each batch of cheese was made using between 135 and 170 L of milk maintained at 32 °C in a 227 L cheese vat. Lyophilized mesophilic direct vat set starter culture (R704, 50 units, Chr. Hansen, Inc., Milwaukee, WI) and single-strength rennet (10.6 mL of rennet per 100 L of milk; Chymax; Chr. Hansen, Inc.) were added to the milk and then allowed to coagulate. The curd was cut using 1.6 cm wire knives and allowed to heal for 5 min. The temperature was gradually raised to 39 °C over 30 min, and the curd was cooked for 90 min, resulting in a firm curd. A majority of the whey was drained, and cold water was added to wash the curd and to bring the temperature of the whey to 30 °C. The curds were soaked for 5 min before the whey was completely drained. Curds were salted at a rate of 2.5% of curd weight and placed into150 × 150 mm cylindrical plastic molds and pressed at 40 psi overnight at room temperature in a vertical cheese press (pneumatic press, Kusel Equipment Co., Watertown, WI). Cheeses were removed from the molds, cut into disks 50 mm in height, and vacuum packed in plastic pouches (FreshPak 500 vacuum pouches, Koch Supply, Kansas City, MO) using a vacuum packager (Koch Ultravac 250, Koch Supply). Cheeses were packed in a cooler with ice packs and sent to the Dairy Processing and Products Research Unit, Eastern Regional Research Center, USDA, Wyndmoor, PA, via overnight delivery. Upon arrival, cheeses were divided into smaller units and repacked as described before and stored at 4 °C for up to 26 weeks.

Cheese Composition. Proximal analysis determined the composition of the cheeses. Moisture content was measured in triplicate on fresh samples using a forced-draft oven method (*18*). Fat content was determined in duplicate using a modified Babcock method (*18*). Nitrogen content was measured in duplicate using the Kjeldahl method (*18*). Salt was determined in triplicate using Quantab strips as described in AOAC 971.19 (*18*). Protein content was calculated by multiplying the nitrogen content by 6.38.

Proteolysis. Proteins were extracted from the cheeses after 1, 4, 8, 16, and 26 weeks of storage according to the procedure described by Tunick et al. (*19*). Approximately 2 g of grated sample in 5 mL of Tris-EDTA buffer (0.166 M Tris, 0.001 M EDTA, pH 8) was homogenized (model 23, VirTis Co., Gardiner, NY) for 15 min before 5 mL of 7% SDS was added, and the mixture was homogenized for an additional 5 min. After homogenization, 2 mL of 0.01 M dithiothreitol was added, and the mixture was placed on ice for 20 min before centrifugation at 39000*g* for 60 min at 4 °C. The supernate was filtered and then lyophilized.

Lyophilized samples were prepared for SDS-PAGE according to the method of Tunick et al. (*20*). A portion of lyophilized sample (0.5 mg) was dissolved in 100 μL of a solution containing 80 mM Tris, 0.5 M EDTA, and 3.5% SDS, pH 8.0, boiled for 5 min, and then cooled before 10 μL of mercaptoethanol and 10 μL of 0.25% tracking dye were added. Proteins were separated on 20% homogeneous ultrathin precast polyacrylamide gels using the PhastSystem (Amersham Pharmacia Biotechnolgy, Piscataway, NJ). Gels were stained in Coomassie Blue, destained in 6:3:1 water/methanol/acetic acid solution and then were scanned into a densitometer with Image Quant software (Molecular Dynamics Personal Densitometer, SI model 375A, Molecular Dynamics, Sunnyvale, CA). Software generated density graphs (two graphs per lane) and calculated areas under the peaks. Protein peaks were identified as α_{s1}-casein (CN), α_{s2}-CN, β-CN, κ-CN, α-lactalbumin (α-LA), and β-lactoglobulin (β-LG). Peptides were quantified in molecular mass ranges of 22−18, 18−15, and <14 kDa. Protein/peptide concentrations were based on means collected from four different lines/two samples.

Rheological Assays. Rheological properties of the cheeses were tested after 1, 4, 8, 16, and 26 weeks of storage according to the procedures described by Tunick et al. (*13*, *19*). All cheese blocks were warmed to 22 °C before samples were removed from the interior of the block.

SAOSA was conducted on triplicate samples using a Rheometrics Dynamic Analyzer (model RDA-700, Rheometrics Scientific, Piscataway, NJ) according to the method of Tunick et al. (*13*). Samples (25.4 × 4−5 mm) were glued between two disks, and a frequency sweep was conducted at 0.2% strain and 1, 10, and 100 rad/s; data collected at 10 rad/s are presented. Instrument software was used to determine elastic modulus (G'), viscous modulus (G''), and complex viscosity (eta*).

TPA of samples was conducted using a Sintech Universal Testing Machine (model SM-25-155, Material Testing Products Systems Corp., Eden Prairie, MN) according to the method of Tunick et al. (*13*). Four cylindrical plugs (14.5 mm in diameter and height) were compressed by 75% twice at a crosshead speed of 100 mm/min. Instrument software uses the force−time TPA curve to calculate hardness (maximum force in first compression required to obtain 75% compression, in N), springiness (height of sample recovery after first compression and before the start of the second, in mm), and cohesiveness (ratio of positive force area of second peak to first peak).

Torsion data were collected using a Torsion Gelometer (Gel Consultants, Inc., Raleigh, NC) operating at 2.5 rpm according to the procedure described by Hamann (*20*) and Tunick and Van Hekken (*21*). Sample plugs were cut and milled to the appropriate capstan shape. A sample was placed in the Gelometer and twisted until the sample fractured. Instrument software measured the maximum shear stress and maximum shear strain at the point of fracture and calculated the shear rigidity (stress/strain). Tests were performed in triplicate.

Statistical Analysis. Experimental data on rheology and proteolysis of the cheeses were analyzed using General Linear Models, and means comparisons were tested using the Bonferroni *t* test (*22*). Differences are stated as significant if $P < 0.05$. Correlations were determined using Microsoft Excel software, CORREL function.

RESULTS AND DISCUSSION

Cheese Composition. The average composition of the goat's milk Monterey Jack cheese was 44.6 ± 1.0% moisture, 55.4 ± 1.0% solids, 28.5 ± 1.2% protein, 24.2 ± 1.8% fat, and 1.03 ± 0.46% salt. The goat cheese in the present study was higher in both moisture and protein content than the 41.9% moisture and 22.6% protein reported in the previous study on commercial goat's milk Monterey Jack cheese (*16*). Other sources of Monterey Jack composition report on cheeses made from cow's milk as having 40−41% moisture, 30−33% fat, and 52% dry matter (*15*, *23*). The slight differences noted in the cheeses are most likely due to slight differences in manufacture. Composition has a major impact on the rheological properties of cheeses as subtle shifts in the protein and fat levels alter the protein matrix that forms the internal structure of the cheese curd.

Proteolysis. The protein profiles obtained using SDS-PAGE are shown in **Figure 1**, and densitometer protein−peptide distribution analysis is summarized in **Table 1**. SDS-PAGE utilizes the charge-neutralizing properties of SDS to separate the proteins and peptides according to relative molecular mass. Cow's skim milk (lane 1) was used as the reference for milk protein (slowest to fastest migration rates) minor whey proteins > α_{s2}-CN > α_{s1}-CN > β-CN > κ-CN > β-LG > α-LA. Acid-precipitated goat casein (lane 2) from the university herd showed bands for α_{s2}-CN, β-CN, and κ-CN. Besides the obvious lack of α_{s1}-CN, the goat protein profile was very similar to the cow protein profile. The slight differences noted in the migration rate of β-CN were due to the slight molecular mass differences due to different amino acid sequences (goat 207 aa, cow 209 aa) and levels of phosphorylation (*4*).

Table 1. Summary of Protein Distributions in Cow's Skim Milk, Goat Casein, and Goat's Milk Monterey Jack Cheese over 26 Weeks of Storage at 4 °C[a]

protein identification	estimated molecular mass (kDa)	skim milk (cow) (%)	casein standard (goat) (%)	week				
				1 (%)	4 (%)	8 (%)	16 (%)	26 (%)
α_{s1}-casein	24	27	0	0	0	0	0	0
α_{s2}-casein	23.7	4	18	13	10	6	3	2
β-casein	24.5	24	51	64	46	41	31	21
κ-casein	19	8	16	0	0	0	0	0
casein fragments								
	22–18	4	6	8	22	40	49	40
	18–15	2	0	11	14	9	10	19
	<14	3	2	4	5	4	5	17
casein protein:casein fragments				3.3	1.4	0.9	0.5	0.3
whey proteins		28	4					
α-LA and β-LG								

[a] Protein profiles were obtained on 20% homogeneous ultrathin gels using SDS-PAGE, and scanned images were used for densitometer analyses.

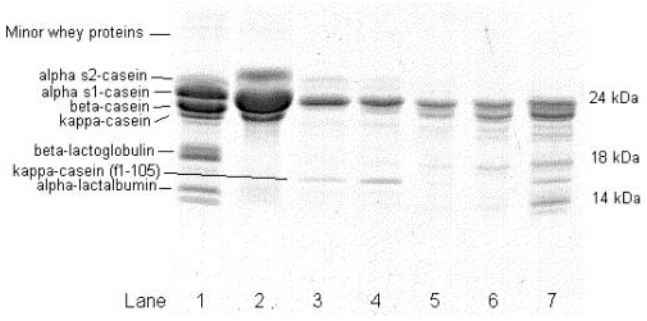

Figure 1. SDS-PAGE of protein extracted from goat's milk Monterey Jack cheese over 26 weeks of storage at 4 °C. Proteins were extracted from cheese in SDS buffers, separated on 20% homogeneous ultrathin polyacrylamide gel, and stained in Coomassie blue: (lane 1) skim milk (bovine); (lane 2) casein (caprine); (lane 3) week 1; (lane 4) week 4; (lane 5) week 8; (lane 6) week 16; (lane 7) week 26. CN, casein; LA, lactalbumin; LG, lactoglobulin.

In fresh goat's milk Monterey Jack cheese (1 week old, lane 3), protein profiles showed a major β-CN band and a minor α_{s2}-CN band; no κ-CN, β-LG, or α-LA bands were present. As the cheese aged (week 1, lane 3; week 4, lane 4; week 8, lane 5; week 16, lane 6; and week 26, lane 7), the β-CN levels decreased significantly (from 64 to 21%), as did the α_{s2}-CN levels (from 13 to 2%).

Trujillo et al. (*3*−*5*) have shown that the hydrolysis of goat casein by rennet and pepsin results in certain sized peptides that can be identified by their migration rates (related to molecular mass) on the SDS-PAGE. In this study, the ranges are loosely identified as 22−18 kDa (migrating in front of β-CN and behind β-LG), 18−15 kDa (migrating near β-LG to just behind α-LA), and <14 kDa (migrating in front of α-LA). This study discusses the major peptides that appear in these ranges, although other casein fragments, currently unidentified, may also be present in the ranges.

The majority of the casein fragments formed during storage were found in the 22−18 kDa range. According to Trujillo et al. (*3*−*5*), this is where the larger peptides from β-CN hydrolysis would be found, including the chymosin-generated series of β-CN (f1-192) (f1-163), and (f1-139) and plasmin-generated β-CN (f29-207). The concentration of smaller casein fragments (in the range of 18−15 kDa) varied over storage and included the κ-CN (f1-105) fragment that slowly decreased as other small peptides from the hydrolysis of β-CN increased. The levels of fragments smaller than 14 kDa slowly increased with storage and included β-CN (f106-207) and (f108-207). Trujillo et al. (*5*) reported that the hydrolysis of α_{s2}-CN by rennet resulted in the appearance of low molecular weight bands in this region. Ratios of intact (native) caseins to casein fragments (see **Table 1**) decreased rapidly during the first 8 weeks of aging (from 3.3 to 0.9) and then decreased to 0.3 by the end of the study.

In cheese, the caseins form a protein network that gives the cheese its structure and form. The organization and strength of that network depends on the ratio of the native caseins and the degree of proteolysis of those proteins. In studies that compared goat's milk that contained zero or high (up to 5 g kg^{-1}) levels of α_{s1}-CN, the milks that contained α_{s1}-CN had firmer milk gels (*7*, *24*), higher cheese yields (*24*), and higher firming rates (*7*). Also, many studies used urea-PAGE to evaluate the proteolysis as goat β-CN contains either five or six phosphates covalently bound to the protein. Trujillo et al. (*3*−*5*) published SDS-PAGE profiles of goat's milk hydrolyzed with rennet, chymosin, or pepsin. Although earlier studies of hard, semihard, and soft goat's milk cheeses, which included Monterey Jack (*10*, *12*, *16*), looked at SDS-PAGE protein profiles, the changes in the profiles were not related to the rheology of the cheese.

Rheology. Rheology is another way to analyze the protein structure by measuring the cheese's response to applied stress or strain (*25*).

SAOSA applies oscillatory small strain to the sample to measure the strength and flexibility of the internal bonds to this nondestructive strain and provides quantitative values for the viscoelastic properties of the cheese matrices. The small-strain dynamic analysis results are summarized in **Figure 2**. The G', G'', and eta* of the cheeses showed similar trends over the 26 weeks of storage. Viscoelastic properties significantly increased over the first 4−8 weeks of storage and then remained constant for the rest of the 26 weeks of storage. The major difference between the viscoelastic properties was the magnitude of the responses. G', which measures the energy stored or the elastic properties of the cheeses, increased significantly from 13.8 to 35.1 kPa over the first 8 weeks. G'', which measures the energy lost or the flow properties of the cheeses, increased significantly from 4.17 to 12.7 kPa over the first 4 weeks. eta*, which measures the phase relationships (G''/G'), increased significantly from 1.44 to 3.91 kPa·s over the first 8 weeks. The SAOSA and proteolysis data showed high correlation (**Table 2**) as the elastic (G') and complex viscosity (eta*) properties of the cheese increased, the concentration of peptides in the 22−18 kDa range also increased (correlations of 0.92 and 0.90, respectively). This is expected as proteolysis of caseins disrupts the protein bonds and the cheese matrix becomes more flexible.

TPA uses a double-compression method to mimic chewing and provides information on the hardness, springiness, and

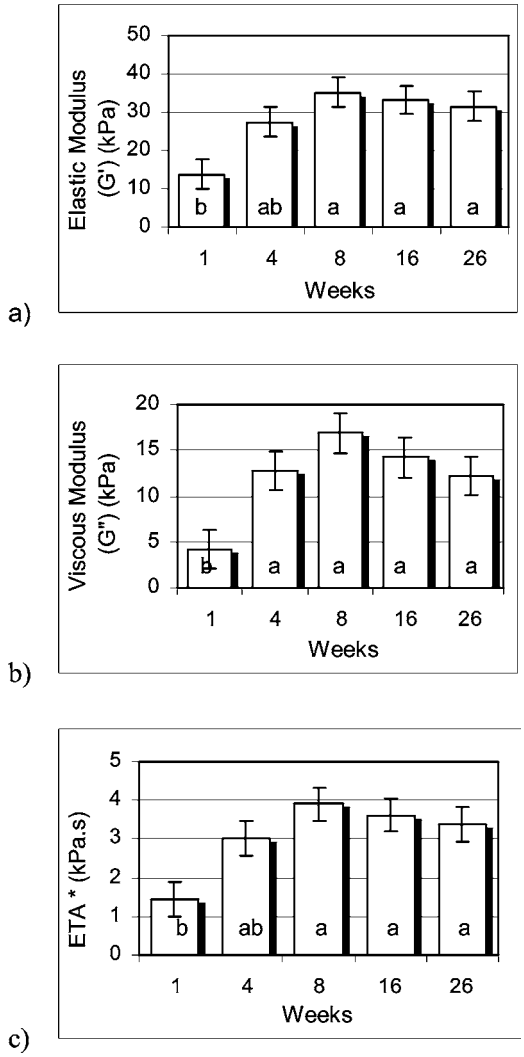

Figure 2. Viscoelastic properties [(**a**) elastic modulus, *G′*; (**b**) viscous modulus, *G″*; and (**c**) complex viscosity, eta*] of goat's milk Monterey Jack cheese over 26 weeks of storage at 4 °C. Data were collected using a Dynamic Analyzer to conduct a frequency sweep at a strain of 0.8% and 1, 10, and 100 rad/s; data from 10 rad/s are presented. Standard error bars, columns with similar letters are not significantly different ($P < 0.05$).

Table 2. Summary of Correlation Factors ($P < 0.05$) among Proteins and Peptide Concentrations and Rheological Properties

	proteins		peptides (kDa)			protein:
rheological property	α_{s2}–CN	β-CN	22–18	18–15	<14	peptide
SAOSA						
elastic modulus, *G′*	–0.84	–0.81	0.92	0.01	0.29	–0.95
viscous modulus, *G″*	–0.68	–0.65	0.82	–0.14	0.09	–0.86
complex viscosity, eta*	–0.81	–0.78	0.90	–0.02	0.25	–0.93
TPA						
hardness	0.99	0.97	–0.96	–0.26	–0.59	0.96
springiness	–0.79	–0.91	0.70	0.62	0.71	–0.90
cohesiveness	–0.83	–0.80	0.85	0.14	0.33	–0.83
TA						
shear stress	0.89	0.92	–0.86	–0.31	–0.60	0.95
shear strain	–0.67	–0.64	0.83	–0.17	0.01	–0.84
shear rigidity	0.87	0.88	–0.90	–0.17	–0.42	0.98

cohesive nature of the cheese. The TPA results are summarized in **Figure 3**. The hardness of the cheese decreased significantly from 43.4 to 26.7 N over the first 8 weeks of storage. No significant differences ($P < 0.05$) were found between 8 and

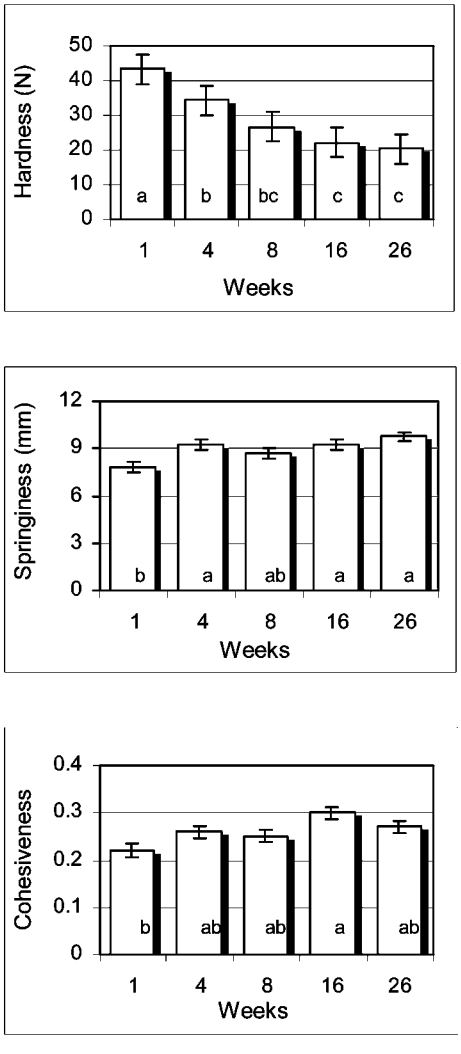

Figure 3. Texture profile analysis properties [(**a**) hardness, (**b**) springiness, and (**c**) cohesiveness] of goat's milk Monterey Jack cheese over 26 weeks of storage at 4°C. Data were collected using a Universal Testing Machine, operated with a crosshead speed of 100 mm/min and 75% compression. Standard error bars, columns with similar letters are not significantly different ($P < 0.05$).

26 weeks of storage. The springiness of the cheese increased significantly from 7.8 to 9.2 mm over the first 4 weeks of storage and then did not change significantly over the next 5 months of storage. The cheese had the lowest cohesiveness after only 1 week of storage and was significantly lower than the cohesiveness of cheese aged for 16 weeks. Hardness of the cheese was correlated (**Table 2**) to β-CN (0.97) and α_{s2}-CN (0.99) and negatively correlated to the peptides in the 22−18 kDa range (−0.91).

Torsion analysis twists the sample to the point of fracture to obtain data on the strength of the gel and the amount of deformation the matrix can tolerate before fracturing. The torsion analysis results are summarized are in **Figure 4**. The shear stress at point of fracture and the shear rigidity (stress/strain) at the point of fracture had similar trends and significantly decreased over the first 8 weeks of storage but did not change significantly over the rest of the study. Between weeks 1 and 8, shear stress decreased from 28.4 to 18.3 kPa and shear rigidity decreased from 29.4 to 14.9 kPa. The shear strain at point of fracture significantly increased from 0.97 to 1.20 over the first 4 weeks of storage, peaked at 1.28 at 16 weeks, and then significantly decreased to 1.14 at week 26. Shear stress at the point of fracture

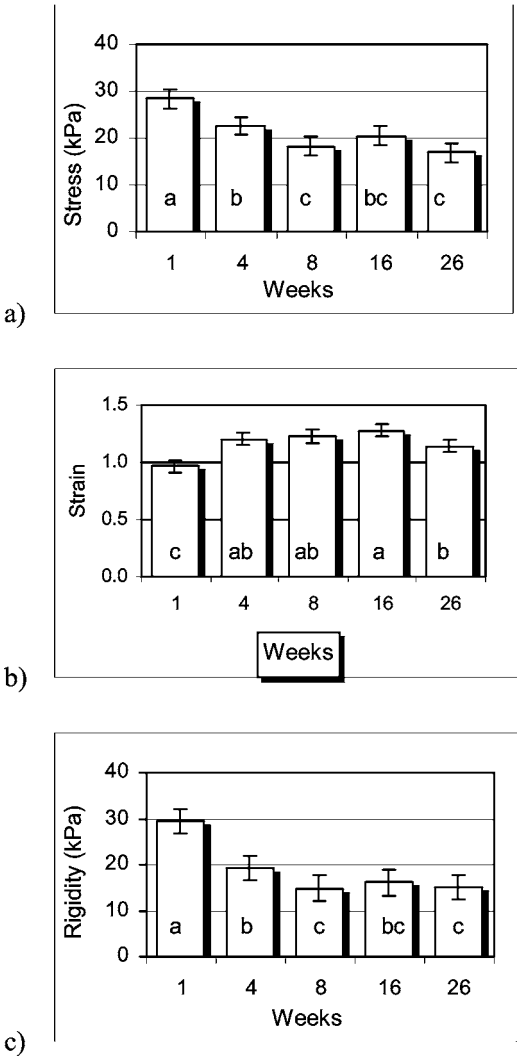

Figure 4. Torsion analysis properties [(**a**) shear stress, (**b**) shear strain, and (**c**) shear rigidity at point of fracture] of goat's milk Monterey Jack cheese over 26 weeks of storage at 4 °C. Data were collected using a Gelometer, operating at 2.5 rpm. Standard error bars, columns with similar letters are not significantly different ($P < 0.05$).

correlated (see **Table 2**) with β-CN (0.92), and shear rigidity correlated negatively to the large peptides at 22−18 kDa (−0.90).

The shear stress and shear strain from the torsion study are plotted on a texture map in **Figure 5**. Cheese became more rubbery as it aged. The largest change in texture was during the first 4 weeks of storage. By 8 weeks of storage, the texture had become fairly stable. After 26 weeks of storage, the cheese tended to shift toward slightly more mushy texture.

The Gelometer measures the shear stress at point of fracture of the cheese and indicates the force required to fracture the sample. It relates gel hardness to protein integrity and concentration and is similar to TPA hardness, with both showing similar decreasing trends as the cheeses age (*20*). As cheese ages, the protein undergoes proteolysis and peptide levels increase. In this study, ratios of protein:peptides decreased from 3.3 at week 1 to 0.3 at week 26 and were correlationed (see **Table 2**) to shear stress (0.95), shear rigidity (0.98), and hardness (0.96). Shear strain at the point of facture of the cheese relates to the deformation a sample requires for structural failure and is similar to TPA cohesiveness. In this study, both increased with aging (torsion analysis showed more significant change for this

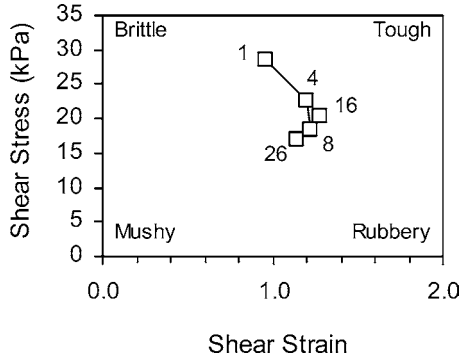

Figure 5. Texture map (shear stress versus shear strain at point of fracture) of goat's milk Monterey Jack cheese over 26 weeks of storage at 4 °C.

property) and had weaker negative correlations to protein:peptide ratios (shear strain, −0.84; cohesiveness, −0.83). This can be related to increased proteolysis altering the rigid structure of the cheese protein matrix, making it more flexible with aging and able to withstand more deformation before breaking. This is supported by the increasing viscoelastic properties tested using small-strain deformations and resulted in high negative correlations between protein:peptide ratios and G' (−0.95) and eta* (−0.93).

Rheological properties are influenced by many factors, including cheese variety and the selected test method and test parameters (*25*). For example, Mozzarella cheese studies showed significant changes in meltability, hardness, springiness, and viscoelastic properties for cheeses made with cheese milk that had different fat contents or different levels of milk protein fortifications or had been homogenized (*13*, *19*, *26*). Very few rheological data are available for comparison on goat's milk cheeses, especially the Monterey Jack variety. Monterey Jack is made using a modified Cheddar cheese procedure (*17*), but it has a higher moisture content (Cheddar is <39% moisture and >50% fat on dry basis), which makes it difficult to compare their rheological properties. In a study of goat's milk Cheddar-like cheese, Attaie et al. (*14*) reported that on cheese with a composition of 36−40% moisture and 30−32% fat, the initial force required to compress the sample 50% was 145 N, whereas for 95% compression, the force required was 760 N. In another study (*24*), high-moisture (53 and 59%) goat's milk cheeses had significantly lower TPA results (study did not mention percent compression used in TPA tests). As more quantitative data are published on the rheological properties of goat's milk cheese, a better understanding of the cheeses' textural quality will be established.

As cheeses age, the protein matrix undergoes proteolysis. The components that make up the cheese undergo rearrangement of bonds, associations, and interactions that result in the intrastructure of the cheese being altered. Our study showed most of the changes occurred over the first 8 weeks. This corresponds to the decrease of native caseins and the formation of peptides shown in the SDS-PAGE. Cheese became more elastic and cohesive as reflected by increased G', shear strain, and cohesiveness. Cheeses were also becoming more viscous as seen by increased G'' and eta*. As the cheeses aged, they became softer as seen by decreased hardness and shear stress and tended to become more rubbery. By 26 weeks of storage the texture started to shift to mushy, indicating a decrease in cheese matrix strength and organization.

The changes in the protein profiles and the rheological properties of goat's milk Monterey Jack cheese illustrate the

complex relationships that are involved in studying the texture of aging semihard cheeses. As more quantitative information is accumulated on the texture, the quality traits of goat's milk cheeses can be better defined, and new cheesemaking techniques can be explored to improve the manufacture of and to ensure the high quality of goat's milk cheeses.

ACKNOWLEDGMENT

We thank J. Shieh for his contribution in collecting SAOSA data and M. Wildermuth for her assistance with the PAGE analysis. We extend our appreciation to S. J. Lee, J. H. Lee, S. Miller, and R. Ragan for their assistance in milk and cheese processing and cheese sample preparation.

LITERATURE CITED

(1) Haenlein, G. F. W. Status and prospects of the dairy goat industry in the U.S. *J. Anim. Sci.* **1996**, *74*, 1173−1181.
(2) Awad, S.; Luthi-Peng, Q. Q.; Puhan, Z. Proteolytic activities of chymosin and porcine pepsin on buffalo, cow, and goat whole and β-casein fractions. *J. Agric. Food Chem.* **1998**, *46*, 4997−5007.
(3) Trujillo, A. J.; Guamis, B.; Carretero, C. Proteolysis of goat β-casein by calf rennet under various factors affecting the cheese ripening process. *J. Agric. Food Chem.* **1995**, *43*, 1472−1478.
(4) Trujillo, A. J.; Guamis, B.; Carretero, C. Hydrolysis of caprine β-casein by plasmin. *J. Dairy Sci.* **1997**, *80*, 2258−2263.
(5) Trujillo, A. J.; Guamis, B.; Carretero, C. Proteolysis of goat casein by calf rennet. *Int. Dairy J.* **1997**, *7*, 579−588.
(6) Clark, S.; Sherbon, J. W. Genetic variants of α_{s1}-CN in goat milk: breed distribution and associations with milk composition and coagulation properties. *Small Ruminant Res.* **2000**, *38*, 135−143.
(7) Pierre, A.; Le Quere, J. L.; Riaublanc, A.; Le Graet, Y.; Demaizieres, D.; Michel, F. Composition and physico-chemical characteristics of goat milks containing the A or $O_{\alpha s1}$-casein variants. *Lait* **1998**, *78*, 191−202.
(8) Tziboula, A.; Horne, D. S. The role of α_{s1}-casein in the structure of caprine casein micelles. *Int. Dairy J.* **1999**, *9*, 173−178.
(9) Carretero, C.; Trujillo, A. J.; Mor-Mur, M.; Pla, R.; Guamis, B. Electrophoretic study of casein breakdown during ripening of goat's milk cheese. *J. Agric. Food Chem.* **1994**, *42*, 1546−1550.
(10) Jin, Y. K.; Park, Y. W. SDS-PAGE of proteins in goat milk cheeses ripened under different conditions. *J. Food Sci.* **1996**, *61*, 490−494, 503.
(11) Park, Y. W. Proteolysis and lipolysis of goat milk cheese. *J. Dairy Sci.* **2001**, *84* (E-Suppl.), E84−E92.
(12) Park, Y. W.; Jin, Y. K. Proteolytic patterns of Caciotta and Monterey Jack hard goat milk cheeses as evaluated by SDS-PAGE and densitometric analysis. *Small Ruminant Res.* **1998**, *28*, 263−272.
(13) Tunick, M. H.; Van Hekken, D. L.; Smith, P. W.; Malin, E. L.; Holsinger, V. H. Characteristics of Mozzarella cheeses made with fortified milk or nonfat dry milk. *Milchwissenschaft* **2000**, *55*, 450−453.
(14) Attaie, R.; Richter, R. L.; Risch, E. Manufacturing parameters and rheological characteristics of Cheddar-like hard goat cheese. *J. Dairy Sci.* **1996**, *79*, 1−7.
(15) Carbery. Monterey Jack Cheese. Carbery Group, 2001; www.carbery.co/products/cheese/monterey-jack.html.
(16) Jin, Y. K.; Park, Y. W. Effects of aging time and temperature on proteolysis of commercial goat milk cheeses produced in the United States. *J. Dairy Sci.* **1995**, *78*, 2598−2608.
(17) Kosikowski, F. V.; Mistry, V. V. Cheddar cheese and related types. In *Cheese and Fermented Foods*, 3rd ed.; F. V. Kosikowski, L.L.C. AVI: Westport, CT, 1997; Vol. 2, pp 104−105.
(18) AOAC. In *Official Methods of Analysis*, 14th ed.; Association of Official Analytical Chemists: Washington, DC, 1984; 43.292, 7.001, 7.009, 7.006, 971.19.
(19) Tunick, M. H.; Malin, E. L.; Smith, P. W.; Holsinger, V. H. Effects of skim milk homogenization on proteolysis and rheology of Mozzarella cheese. *Int. Dairy J.* **1995**, *5*, 483−491.
(20) Hamann, D. D. Rheology as a means of evaluating muscle functionality of processed foods. *Food Technol.* **1988**, *42*, 66−71.
(21) Tunick, M. H.; Van Hekken, D. L. Torsion gelometry of cheese. *J. Dairy Sci.* **2002**, *85*, 2743−2749.
(22) SAS Institute Inc. In *SAS System for Windows*, release 6.12; SAS Institute Inc.: Cary, NC, 1996.
(23) Drake, M. A.; Herrett, W.; Boylston, T. D.; Swanson, B. G. Sensory evaluation of reduced fat cheeses. *J. Food Sci.* **1995**, *60*, 898−901, 905.
(24) Pirisi, A.; Colin, O.; Laurent, F.; Scher, J.; Parmentier, M. R. Comparison of milk composition, cheesemaking properties and textural characteristics of the cheese from two groups of goats with a high or low rate of α_{s1}-casein synthesis. *Int. Dairy J.* **1994**, *4*, 329−345.
(25) Tunick, M. H.; Nolan, E. J. Rheology of Cheese. In *Physical Chemistry of Food Processes*; Baianu, I. C., Ed.; Van Nostrand Reinhold: New York, 1993; Vol. 1, pp 273−297.
(26) Tunick, M. H.; Mackey, K. L.; Shieh, J. J.; Smith, P. W.; Cooke, P.; Malin, E. L. Rheology and microstructure of low-fat Mozzarella cheese. *Int. Dairy J.* **1993**, *3*, 649−662.

Received for review January 15, 2004. Revised manuscript received May 28, 2004. Accepted June 10, 2004. Mention of brand or firm names does not constitute an endorsement by the U.S. Department of Agriculture over others of a similar nature not mentioned.

JF049918Q