Estimating Softening Point of Cheeses[1]

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ABSTRACT

Two objective test methods for determining the softening point of cheeses, accounting for both rheological and thermal characteristics, were developed. An apparatus operated on modified squeeze-flow configuration for evaluating softening and flow characteristics of cheeses was used to determine the softening point of cheeses. A device, UW Meltmeter, operated on squeeze-flow configuration for evaluating melt and flow characteristics of cheese was also used to determine the softening point of cheeses. Results from both methods agreed well. The effects of oven temperature (60 to 80°C) and fat (1.6 to 33.6%), moisture content (53 to 59%), and aging (1 to 12 wk) of the cheese on the softening point were investigated. The softening point of cheese increased with reduction in fat content of cheese and increased oven temperature. In general, the softening point of cheese decreased with age of cheese.
(**Key words:** softening, cheese, Cheddar, Mozzarella)

Abbreviation key: $\mathbf{T_s}$ = Softening point, **FDM** = fat in the dry matter, **LVDT** = linear variable differential transformer.

INTRODUCTION

Use of cheese as an ingredient in prepared foods is increasing. A recent survey showed that 421 new cheeses were introduced in 1996, up 70% from 1995 (11). Concomitant with this increase has been an increased need for characterizing the behavior of cheeses at elevated temperatures. Normally, the focus has been on characterizing and measuring the meltability—a property that causes cheeses to flow at high temperatures. In many applications, however, cheeses are needed that soften but do not melt and flow.

Conventional meltability tests are mainly based on controlled heating of cylindrical samples and measuring flow or changes in height or diameter. The most commonly reported methods for meltability assessment are those described by Olson and Price (19), Kosikowski (16), and Arnott et al. (2). The method proposed by Kosikowski (16), known as the Schreiber's test, is the most widely used in the industry.

Many basic methods are available for rheological analyses of materials other than foodstuffs, which could be successfully used for studying the behavior of melted cheese (23). For example, Smith et al. (25) showed that capillary rheometry is appropriate for estimating cheese flowability. About a decade ago, Casiraghi et al. (6) and Campanella et al. (5) reported elongational viscosity data for Mozzarella cheese and American processed cheese from squeezing flow tests and have related such measurements to cheese meltability. Ustunol et al. (26) used small amplitude oscillatory shear tests and has correlated minimum complex modulus with meltability of Cheddar cheese.

The main problem, in objective determination of the attributes commonly comprised within "meltability," is that they are related to heat transfer and thermal phase change characteristics of the solid cheese and to rheological or flow properties of the melt. These characteristics are highly interdependent and transient properties. Park et al. (20) compared two traditional cheese meltability tests, the Schreiber and Arnott, on a variety of cheeses. A marked lack of correlation was found between the Schreiber and Arnott results. The results mainly reflected the test geometry and rheological properties of melt and, to a lesser extent, the effects of the transient stage prior to full melting. They further concluded that in any meltability evaluation, the rheological and thermal aspects ought to be considered as equally important and that no single parameter could meaningfully account for both. Recently we developed a device, the UW Meltmeter, to objectively evaluate the melt and flow characteristics of cheeses (29). This device offered such advantages as controlled heating, constant sample temperature at the start of a test, and rheologically well defined test and data analysis procedure.

Blumenthal et al. (3) probably was first to use the standard dropping point method to characterize the melting behavior of Raclette cheese. They used the same equipment and technique as described in various

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TABLE 1. Chemical composition of cheeses used in the study.

Cheese type	Fat	Moisture	MNFP[1]	FDM[2]	Salt	S/M[3]	Initial pH
	(%)						
Cheddar	33.0	38.8	57.9	53.9	1.0	2.7	5.1
	20.5	43.0	54.2	36.1	2.0	4.7	5.6
	1.6	53.3	54.1	3.4	1.9	3.6	5.6
Mozzarella	21.7	46.4	59.2	40.4	1.5	3.3	5.2
	7.3	54.0	58.2	15.8	1.6	3.0	5.2
Pizza	22.3	47.0	60.5	42.1	1.6	3.5	5.2
	8.4	54.5	59.6	18.6	1.6	3.0	5.3

[1]Moisture in the nonfat portion.
[2]Fat in the dry matter.
[3]Salt in moisture.

official standards (ASTM D 3461-76) for fat characterization. The dropping point corresponds to the temperature at which the first drop of melted sample falls off a nipple with an orifice diameter of 2.8 mm. In addition to the dropping point, a softening point (**T_s**) was defined and determined for the same samples. The T_s was temperature at which the first drop started to flow out of a nipple with an orifice diameter of 6.4 mm. The method was successfully applied to Raclette cheese and allowed characterization of the melting quality (8). However, the dropping point of only few cheese varieties can be measured without major problems (24). For many cheese varieties, oiling off occurs before the dropping point is reached, or the drop does not fall off because of high viscosity. Difficulties are encountered when testing cheeses such as Mozzarella, which contain droplets of residual whey (23). Because T_s is the temperature at which cheese just begins to flow under constant force when heated, methods that simultaneously account for cheese temperature and flow characteristics would be most appropriate.

The objectives of this study were to

1. develop methods for determining the T_s of cheeses accounting for both rheological and thermal characteristics and
2. investigate the effect of cheese type, heating rate, fat content, and age of the cheeses on the softening point.

MATERIALS AND METHODS

Cheddar, Mozzarella, and pizza cheeses of different fat levels (two lots of each) were manufactured at the Dairy Plant, University of Wisconsin-Madison, Madison. Pizza cheese is a variation of Mozzarella cheese without the usual mixing and molding procedure (7). The cheese blocks were vacuum-sealed in barrier bags (VF-400; Vilutis & Co. Inc, Frankfort, IL) and were stored at 4°C until testing. The composition of the cheeses is presented in Table 1.

A cheese block was cut into slices (~ 7 mm thickness) perpendicular to the long axis of the block (for Mozzarella cheese) using an electric food slicer (Model 1042, Rival® Fold-Up; Rival Electric Food Slicer, Kansas City, MO). Then cylindrical test pieces (~ 30 mm sample diameter) were cut out with a cork borer in a direction parallel to the longitudinal axis. Hence, the fiber orientation in the case of Mozzarella cheese was parallel to the flow direction (1). To obtain a uniform sample size, the slicing and cutting were done immediately after removing the cheese blocks from the refrigerator (6).

Moisture content was determined in a vacuum oven at 100°C for 5 h (27). Fat was determined by the Babcock method (4), salt was determined coulometrically (14) using a Chloride Analyzer 926 (Corning, Medfield, MA), and pH was measured by the gold electrode/quinhydrone method (28). Both pH 4.6-soluble N (10) and TCA-soluble N (13) were measured. The percentage increase in soluble N at different ages (0, 2, 4, and 12 wk) was used as an index of cheese proteolysis. Each measurement was replicated three times.

Based on our success with the squeeze flow technique to measure cheese melt and flow properties (29), we developed two tests: constant temperature and transient temperature.

Constant Temperature Test

This test was performed using the UW Meltmeter. Detailed description of the UW Meltmeter operation is presented in Wang et al. (29). Briefly, the cheese sample was heated to a constant preset temperature and was allowed to flow under a constant force. From the stress and strain rate data collected during the test, initial biaxial stress growth coefficient (η^+_B) of the sample was calculated. To identify the softening point, the UW Meltmeter was operated at eight constant sample temperatures (T), from 30 to 65°C in 5°C steps. At each temperature, the tests were replicated three times.

Transient Temperature Test

A modified squeeze-flow apparatus was designed and developed (Figure 1). It consisted of a linear variable differential transformer (**LVDT**, Model 1000 DC-E; Schaevitz™ Sensors, Hampton, VA) connected to a data acquisition system (21X Micro logger, Campbell Scientific Inc., Logan, UT) and a computer for automatic data collection. The bottom end of the LVDT core was attached to a 67-mm diameter circular plate. The weight of the circular plate (0.7 N) provided the constant force causing the cheese to flow. The test was performed by placing the cheese (diameter ~30 mm and thickness ~7 mm) on a sample platform and lowering the circular disk to be in continuous contact with the cheese. The cheese sample was covered with mineral oil to protect from dehydration during the test.

The apparatus was placed inside a constant temperature cabinet (Blue-M forced-air convection oven, model OV-490A-2; Blue-M Electric Company, Blue Island, IL). Cheese temperature was measured as a function of time during heating by using a copper-constantan (Type T), precision fine-wire thermocouple (diameter = 0.13 mm; Omega Engineering, Inc., Stamford, CT). The thermocouple was inserted from the side of the sample until the tip of the thermocouple reached the center. The LVDT measured the cheese flow data simultaneously with the changing cheese temperature. Three constant oven temperatures of 60, 70, and 80°C were used. These preset oven temperatures imposed different heating rates. Each test was replicated three times.

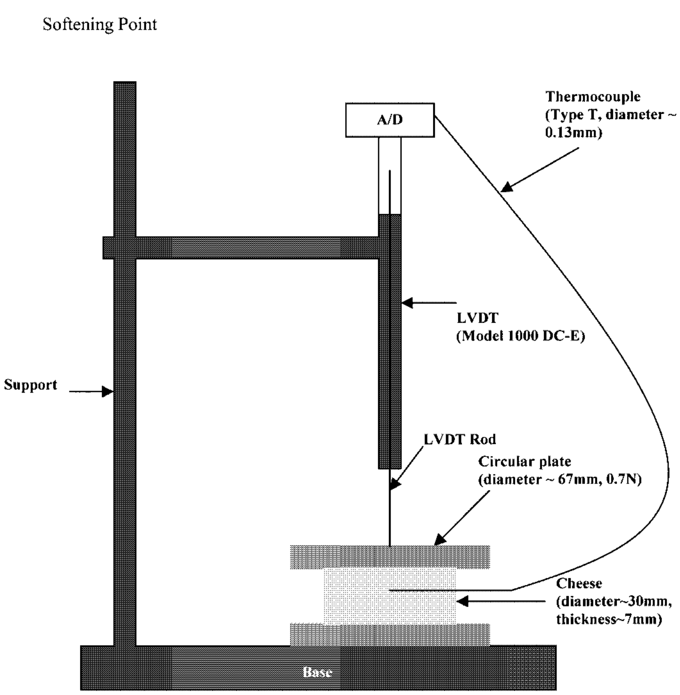

Figure 1. Schematic of a modified squeeze-flow apparatus. A/D = analog-digital converter; LVDT = linear variable differential transformer.

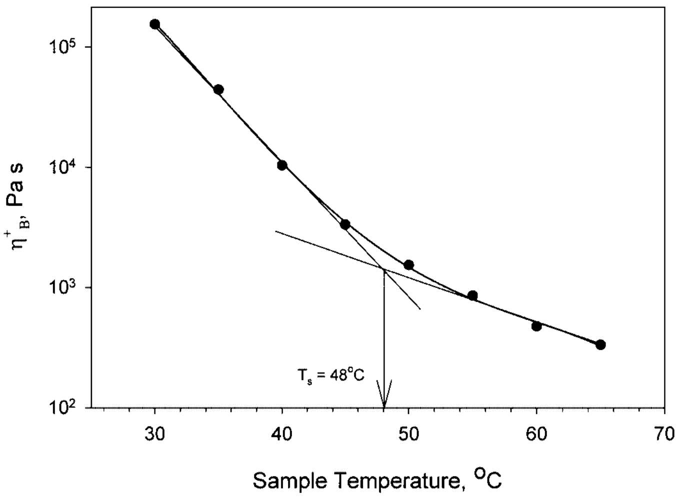

Figure 2. A plot of biaxial stress growth coefficient (η^+_B) versus temperature obtained using UW Meltmeter for Cheddar cheese with 53.9% fat in the dry matter. Softening point was 48°C.

RESULTS AND DISCUSSION

Identifying the T_s

Constant Temperature Test

A typical plot of log (η^+_B) (vs) T is shown in Figure 2. The experimental data presented in Figure 2 was obtained from Cheddar cheese with 53.9% fat in the dry matter (**FDM**). This plot shows two distinct linear regions; the gradient (d log (η^+_B)/dT) was larger initially (gradient = –0.117; r = 0.999) compared with the terminal region (gradient = –0.041; r = 0.998). This finding indicated a transition zone—a region in which the cheese softened and started to flow under constant force. We hypothesized that this transition zone represented the softening of the cheese. Accordingly, the temperature at which transition occurred was identified as T_s.

The T_s could be approximated by either a graphical method or by calculation. In the graphical method, tangents were drawn to the two linear segments, and the temperature corresponding to the point of intersection was identified as T_s (Figure 2). The tangents could either be drawn manually or with a graphical program. Although this method is very easy to apply, it is prone to error.

In the calculation method, the softening point was obtained by setting the third derivative of the log (η^+_B) (vs) T curve to zero (d^3 log (η^+_B)/dT^3 = 0). To avoid the amplification of experimental noise during differentia-

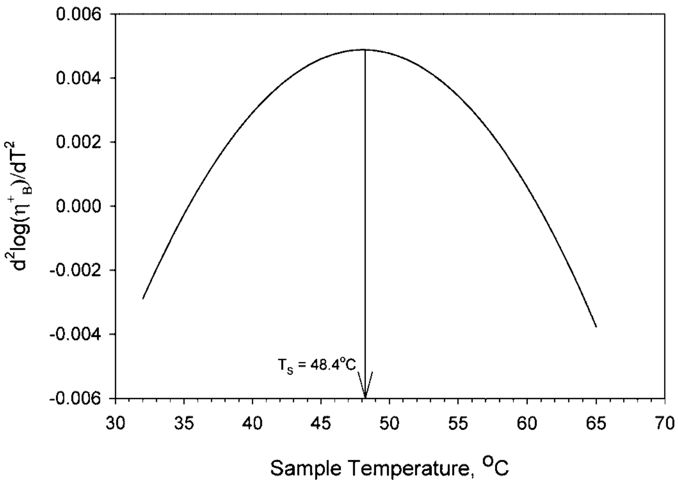

Figure 3. Softening point determination by UW Meltmeter using calculation method for Cheddar cheese with 53.9% fat in the dry matter. Softening point was 48.4°C. $d^2log(\eta^+_B)/dT^2$ = second differential of biaxial stress growth coefficient (η^+_B).

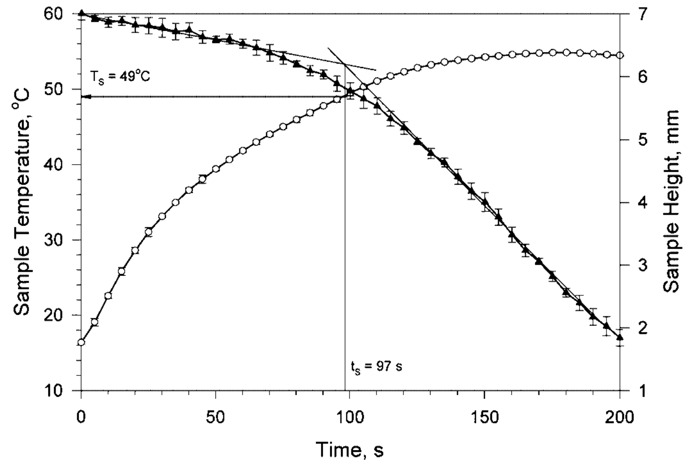

Figure 4. Increase in cheese temperature and simultaneous decrease in height (deformation) with time for Cheddar cheese with 53.9% fat in the dry matter tested at 60°C. The bars at each data point represent the standard deviation. Softening time = 97s, softening point = 49°C, ○ = sample temperature, and ▲ = sample height.

tion and to facilitate data processing, log (η^+_B) (vs) T data were fitted to different models. A fourth-order polynomial model best fit the data (r = 0.99):

$$\text{Log } (\nu^+_B) = a_0 + a_1{*}T + a_2{*}T^2 + a_3{*}T^3 + a_4{*}T^4$$

where a_0, a_1, a_2, a_3, and a_4 are constants. The second differential of the above equation exhibited the maxima of the $d^2 \log (\eta^+_B)/dT^2$ curve (Figure 3). The exact transition point was determined from the third differential as explained below.

$d^3 \log (\eta^+_B)/dT^3 = 6a_3 + 24\ a_4{*}T$,
setting $d^3 \log (\eta^+_B)/dT^3 = 0$, and
$T = T_s = -a_3/4a_4$

The coefficients of the polynomial models used to represent these curves are listed in Table 2.

Transient Temperature Test

A typical plot of increase in cheese temperature (T) and simultaneous decrease in height (H) of sample with time (t) is shown in Figure 4. The experimental data presented in Figure 4 were obtained from Cheddar cheese with 53.9% FDM. The H (vs) t curve clearly showed two different linear deformation parts, namely an initial slow linear deformation region and the later rapid linear deformation region. Thus, identification of softening point using this plot was very similar to the procedures explained above for the constant temperature test. Graphically, temperature corresponding to the point of intersection of tangents drawn of the two linear regions was identified as T_s (Figure 4). For the calculation method, both the H (vs) t and T (vs) t data were modeled using a fourth-order and a fifth-order polynomial, respectively. The softening time (t_S) was determined by setting $d^3H/dt^3 = 0$. The softening point (T_s) was calculated by substituting the t_S for t in the T (vs) t model. The coefficients of the polynomial models used to represent these curves are listed in Table 2.

Both the constant temperature and transient temperature tests gave essentially the same T_s values of approximately 48°C for Cheddar cheese with 53.9% FDM

TABLE 2. Coefficients of polynomials fitted to constant and transient temperature test data presented in Figures 2 and 4.

Test[1]	Model	a_o	a_1	a_2	a_3	a_4	a_5	R^2
CT	$\log(\eta^+_B)$ (vs) T	0.1284	0.7394	−0.0309	4.86e-4	−2.51e-6		0.999
TT	H (vs) t	7.0	−0.013	2.45e-4	−3.16e-6	8.14e-9		0.999
	T (vs) t	15.826	0.8036	−1.005e-2	8.53e-5	−3.84e-7	6.64e-10	0.999

[1]CT = Constant temperature test; TT = transient temperature test; a_o, a_1, a_2, a_3, a_4, a_5 = model coefficients; $\log(\eta^+_B)$ = logarithm of biaxial stress growth coefficient; T = sample temperature; H = sample height; and t = time.

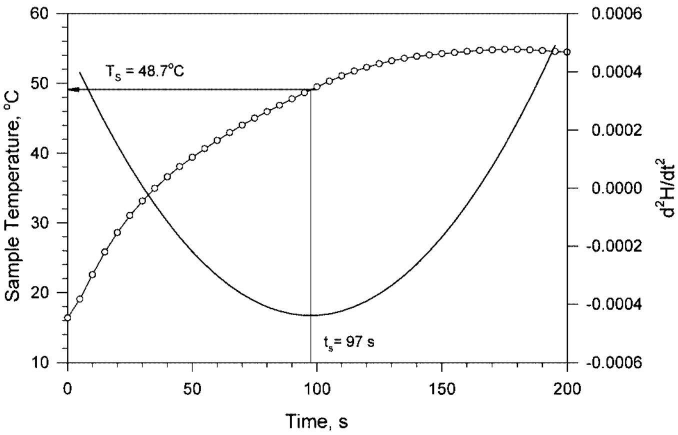

Figure 5. Softening point determination using calculation method for Cheddar cheese with 53.9% fat in the dry matter tested at 60°C. Softening time = 97s, softening point = 48.7°C, ○ = sample temperature, and — = d^2H/dt^2 = second differential of height with time.

(Figures 3 and 5). Although the constant temperature test worked very well, it was very time consuming. The need for conducting multiple tests (at different sample temperatures) required a total of approximately 2 h per sample. But the advantage of the transition temperature test was that it took only 15 min per sample. Because test duration was a critical issue, especially for routine testing in the cheese industry, the transient test was selected as the recommended test method of softening point. Thus, except for one sample, all subsequent tests were performed with only the transient test. The test results could be analyzed either graphically or by calculation after fitting the data to a polynomial.

Effect of Fat Content and Heating Rate on Softening Point

The T_s values for three Cheddar cheeses of different fat levels and oven temperatures are given in Table 3. As FDM increased, T_s of the cheese decreased. This effect was statistically significant ($P < 0.05$). Similar findings have been reported (15, 22) for meltability of Mozzarella cheese in the literature. As the oven temperature increased, T_s of the cheese increased. It appeared that if the cheese was heated quickly a higher temperature could be reached before it softened. The differences were statistically significant for 3.4 and 36.1% FDM Cheddar cheeses but not for the 53.9% FDM sample. The effect of temperature on rheological properties of cheese is often related to the state of the fat globules. The ratio of solid-to-liquid fat is the principal factor determining the rheological properties of the fat. This ratio decreases with increasing temperature (17, 21). At 40°C and above, most fat is liquid and should contribute little to T_s. Recently, Zhou and Mulvaney (30) studied the effect of milk fat, the ratio of casein to water, and temperature on the viscoelastic properties of rennet casein gels. They found that the melting temperature of the casein gels increased as the ratio of casein to water increased; however, the milk fat had less effect. They suggested that the casein:fat system behaves much like a typical filled polymer system, except that the material properties of the filler itself are also temperature dependent. The fat acts as reinforcing filler at low temperatures (<40°C) and gradually becomes a diluting factor or plasticizer of casein melt. The latter probably occurs above approximately 40°C, at which temperature the casein network is substantially dissociated, and the fat is completely liquid. The filled-gel composite model has been used (22) to help understand the changes in the rheological characteristics of cheese as a result of fat reduction. With respect to the filled-gel composite model (22), the fat and moisture represent

TABLE 3. Softening point of 2-wk-old Cheddar cheeses obtained using a transient temperature test.

FDM[1] (%)	Oven temperature (°C)		
	60	70	80
3.4	51^{Ab}	54^{Aa}	55^{Aa}
36.1	49^{Bc}	51^{Bb}	56^{Aa}
53.9	48^{Ba}	49^{Ca}	48^{Ba}

A,B,C Means within each column without a common superscript differ ($P < 0.05$).

a,b,c Means within each row without a common superscript differ ($P < 0.05$).

[1]Fat in the dry matter.

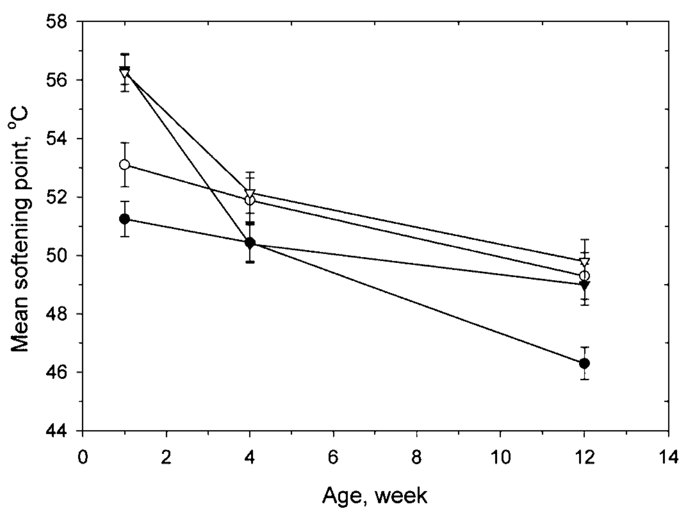

Figure 6. Effect of age of Mozzarella and pizza cheeses on softening point. Samples tested at 60°C. ● = full-fat pizza, ○ = low-fat pizza, ▼ = full-fat Mozzarella, and ▽ = low-fat Mozzarella.

TABLE 4. pH 4.6-soluble N and 12% TCA-soluble N during ripening of four different cheeses.

Age (wk)	pH 4.6-Soluble N[1]				TCA-Soluble N[2]			
	FFP[3]	FFM	LFP	LFM	FFP	FFM	LFP	LFM
0	5.4	5.7	2.6	4.6	59	56	50	42
2	9.1	6.3	8.6	5.0	191	131	167	37
4	12.2	8.8	11.9	6.4	230	224	235	64
12	18.1	13.4	18.6	8.4	436	456	431	193

[1]Expressed as a percentage of total nitrogen.

[2]Expressed as micromoles of glycine equivalent per gram solid nonfat cheese.

[3]FF = full fat, LF = low fat, P = pizza, and M = Mozzarella.

the filler within the casein network (gel). If the fat has no interaction (molecular bonding, colloidal forces, or friction) with the matrix, then, as its volume fraction is decreased, there is more matrix to soften per unit volume, and consequently, the composite should be more difficult to soften and melt. Some unexpected behavior in the squeezing performance of the cheese was only in part due to its material properties, and the thermal properties might have played a quite important and significant role. Further information on thermal properties and chemistry of cheeses varying in composition is needed to better explain the complex phenomena of softening, melting, and flow characteristics of cheeses.

Effect of Cheese Age on Softening Point

Mean T_s values of the Mozzarella and pizza cheeses during 12 wk of storage are shown in Figure 6. During refrigerated storage, T_s values of all cheeses decreased, and both pH 4.6-soluble nitrogen and TCA-soluble nitrogen increased (Figure 6 and Table 4). These observations were similar to previously reported trends on meltability for both low-moisture, part-skim Mozzarella and reduced-fat Mozzarella cheeses (9, 12, 18, 22).

The largest decrease in T_s of the full-fat Mozzarella cheese was from wk 1 to 4, followed by minimal decrease from wk 4 to 12. A similar trend was observed for low-fat Mozzarella cheese. However, for full- and low-fat pizza cheeses, the decrease in T_s was linear from wk 1 to 12. As the fat content of Mozzarella cheese decreased, both pH 4.6-soluble nitrogen and TCA-soluble nitrogen significantly decreased. However, no significant difference was found for soluble nitrogen between the full- and low-fat pizza cheeses. This finding suggests that proteolysis may not be the only causal effect for changes in the T_s of cheeses during storage but also the redistribution of water in cheese during storage (18). It appeared that during the initial weeks of cheese storage, expressible water was transferred from the fat-serum channels of the Mozzarella cheese (stretched cheese) into the protein matrix as the proteins became more hydrated. And some interactions between proteins were replaced with interactions of proteins with the bulk-phase water molecules (18). As expressible water was absorbed into the protein matrix, increased protein hydration from wk 1 to 4 allowed the proteins to soften more when heated and resulted in a greater decrease of T_s. Further decrease of T_s from wk 4 to 12 could have been due to redistribution of water and proteolysis. However, the protein matrix in the full- and low-fat pizza cheeses (pressed cheese) impedes all the water, leaving no expressible water (7).

In general, the pizza cheese had lower T_s values compared with Mozzarella cheese. This trend was presumably due to more moisture in the nonfat portion of pizza cheese than of Mozzarella cheese (Table 1). A decrease in T_s can be considered as an objective indication of increased softening and melting during aging. Hence, a range of T_s values may exist at which cheese is acceptable for numerous ingredient applications.

CONCLUSIONS

Softening point (T_s) of cheese was defined as the temperature at which cheese, when heated, changed from being semisolid to a fairly free flowing fluid. Two test procedures were developed for determining T_s: constant and transient temperature tests. Both tests gave comparable T_s values. However, the transient test required much less time per sample than did the constant temperature test. The data from both tests can be analyzed either graphically or by calculation. The calculation method is recommended, as it is less prone to error than the graphical method. Tests with Cheddar, Mozzarella, and pizza cheeses of different composition and age showed that T_s values increase with reduction in cheese fat content and decrease with cheese aging.

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