J. Dairy Sci. 84:1937–1943

Effect of Heat Treatments on the Meltability of Cheeses

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ABSTRACT

The effect of heat treatments on the meltability of cheese was investigated. Cheddar cheeses of different composition and low-moisture, part-skim Mozzarella cheese were studied at 1, 3, 6, and 12 wk of aging. Cheese samples were heated to 60°C and held for 0, 10, and 20 min before allowing the melted cheese to flow. Mean meltabilities, over all ages, of both Cheddar and Mozzarella cheeses decreased significantly as holding time increased. Meltability of young cheese was scarcely affected by the holding time, in sharp contrast to that of the old cheese where increasing the holding time greatly reduced meltability.
(**Key words:** cheese, meltability)

Abbreviation key: FDM = fat in DM, **LMPS** = low moisture, part skim, **MNFP** = moisture in nonfat portion.

INTRODUCTION

Cheeses are popularly used as ingredients in many prepared, ready-to-eat foods in which the cheese often undergoes melting. Use of Cheddar cheese on toasted sandwiches and Mozzarella cheese on pizza are some familiar examples. Consumer acceptance of these foods depends on the melting quality of the ingredient cheeses. Therefore, the meltability of cheese is an important factor in determining the quality for particular product applications.

The term meltability has been used to indicate the extent to which melted cheese flows and spreads upon heating. Past studies on cheese meltability have mainly focused on the effect of chemical constituents, proteolysis, and some cheesemaking procedures. Arnott et al. (1957) attempted to correlate the melting properties with certain chemical properties of the Cheddar and process cheeses. Moisture and fat contents, pH, and free tryosine levels were not related to the melting quality of Cheddar cheese. No relationship was found between melting quality and fat, moisture, or pH level of process cheese. However, the melting quality was satisfactory when age of cheese, as measured by free tyrosine, was above a given level. Melting properties of both Cheddar and Gouda cheeses were found to be correlated with reduction in casein content (r = –0.92) by Gupta (1972). He reported that ripened cheeses of both varieties had improved melting characteristics compared with fresh cheeses. Bogenrief and Olson (1995) studied the effect of β-casein hydrolysis on meltability of Cheddar cheese. Overall, meltability was positively correlated with β-casein hydrolysis. Impacts of ultrafiltered (Madsen and Qvist, 1998) and homogenized (Tunick et al., 1993) milks, whey pH at draining (Yang et al., 1995a), starter cultures (Hong et al., 1998; Yun et al., 1995b), and coagulant concentration (Kindstedt et al., 1995) on melting characteristic of Mozzarella cheese were investigated by numerous researchers to improve and control cheese meltability.

Feedback from the cheese industry has indicated that temperature history during heating also may affect melting characteristics of cheeses. Wang et al. (1998) studied the effect of melting temperature on the melting characteristics of Mozzarella cheese using a modified squeezing flow apparatus. They reported a lower biaxial extensional viscosity (BEV) and higher biaxial extensional strain rate (BESR) for the Mozzarella cheese at 60°C than at 40°C. The BEV decreased with temperature, indicating a thermal softening of Mozzarella cheese. Similar results were reported by Ak and Gunasekaran (1995). Kim (1999) observed that the viscosity of the melted Cheddar cheese, held at 60°C before allowing it to flow, changed significantly. The change in viscosity of melted cheese depended on holding time at 60°C. One of the reasons for an increase in the viscosity of cheese during heating is thought to be the protein aggregation by hydrophobic interactions among the caseins (Kim, 1999).

Received July 3, 2000.
Accepted September 6, 2000.
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Our objectives were to: 1) investigate the effect of different heating regimes, composition, and age on the meltability of Cheddar cheese, and 2) compare the effect of heat treatments on the meltability of Cheddar and Mozzarella cheeses.

MATERIALS AND METHODS

Meltability Test

A modified squeeze flow apparatus known as the UW Meltmeter (Wang et al., 1998) was used to measure melting behavior of cheese. Cylindrical specimens of cheese, 30-mm diameter and 7-mm height, were cut out with a cork borer and used as described in Kuo et al. (1999).

Preliminary Study

Preliminary studies were conducted to choose meaningful conditions for investigating the effect of heat treatments on cheese meltability. One batch of 3-wk-old full fat Cheddar cheese was obtained from the Dairy Plant of the Food Science Department at University of Wisconsin-Madison. Cheese meltability was measured as a function of temperature (40, 50, and 60°C) and holding time (0, 5, 10, 20, and 40 min). The holding time is the duration over which the heated cheese is held at a certain temperature before it is allowed to flow. All measurements were conducted in triplicate.

Heat Treatment

Based on the preliminary results, the following conditions were chosen to evaluate the effect of heat treatment, composition, and age on cheese meltability: test temperature = 60°C, holding times = 0, 10, and 20 min. Cheddar cheeses of varying composition and brine-salted, low-moisture, part-skim (**LMPS**) Mozzarella cheese were used. The stretching temperature during LMPS manufacture was 76.7°C. Single batch was aged and analyzed for each type of cheese. The fat in dry matter (**FDM**) and moisture in non-fat portion (**MNFP**) of Cheddar cheese were controlled to adjust these two variables independently (Table 1). Cheeses were manufactured in the Dairy Plant of the Food Science Department at University of Wisconsin-Madison. Cheese blocks were vacuum-sealed in barrier bags (VF-400, Vilutis & Co. Inc., Frankfort, IL) and stored at 6 to 8°C. Tests were carried out in triplicates at 1, 3, 6, and 12 wk after production date. To minimize compositional variations among the LMPS cheese samples, the cheese block was cut into four small blocks 1 d after manufacture and, for each test, a randomly selected block was used. The samples were cut such that their fiber orientation was parallel to the direction of compression.

Compositional Analysis of Cheese

The pH was measured by the gold electrode/quinhydrone method (Case et al., 1985). Salt analysis was performed according to the procedure given by Johnson and Olson (1985) with the chloride analyzer (model 926, Corning Glass Works, Medfield, MA). Protein concentration was determined by the Kjeldahl method (Case et al., 1985). Moisture was determined by a vacuum oven technique (Case et al., 1985) and fat by the Babcock test (Case et al., 1985). Samples for compositional analysis were taken when the cheeses were 7 d old. Percentages of FDM and MNFP were calculated (Tunick and Shieh, 1995).

Statistical Analysis

The data were subjected to ANOVA using the general linear models (GLM) of SAS (1989). The statistical model employed for data from Cheddar cheeses with fat and moisture variations was:

$$Y_{ijkl} = \mu + C_i + A_j + T_k + (C \times A)_{ij} + (C \times T)_{ik} + (A \times T)_{jk} + (C \times A \times T)_{ijk} + \varepsilon_{ijkl},$$

Table 1. Compositions of Cheddar and low moisture, part skim (LMPS) Mozzarella cheeses.

Cheese	MNFP	FDM	Salts	Protein	pH
	(%)				
Cheddar					
Fat variation					
Cheese 1	56.0	52.0	1.34	25.2	5.16
Cheese 2	56.5	35.6	1.43	28.0	5.10
Moisture variation					
Cheese 1	46.4	8.43	2.28	43.3	5.45
Cheese 2	53.7	12.7	2.17	36.5	5.28
Cheese 3	56.6	7.72	2.05	34.2	5.14
LMPS Mozzarella	58.0	39.7	1.52	31.8	5.33

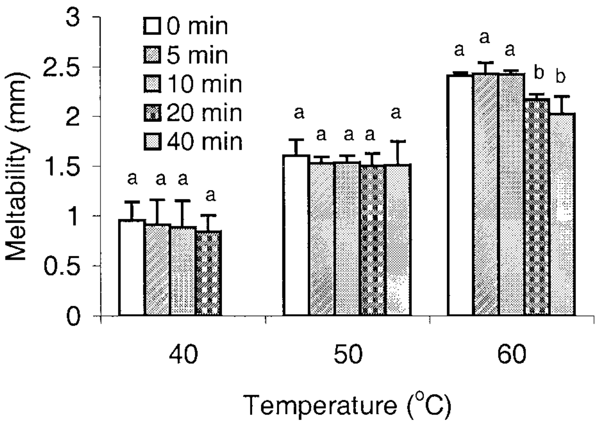

Figure 1. Effect of holding time and temperature on the meltability of 3-wk-old full fat Cheddar cheese. The standard deviation is indicated on top of the bars. [a,b]Different letters indicate significance ($P < 0.05$) between the mean meltability values for holding times within each temperature.

where Y = cheese meltability, μ = reference, C = effect of fat (i = 1 to 2) or moisture (i = 1 to 4) level, A = effect of aging (j = 1 to 4), T = effect of holding time (k = 1 to 3), C × A = effect of fat (or moisture) × aging interaction, C × T = effect of fat (or moisture) × holding time interaction, A × T = effect of aging × holding time interaction, C × A × T = effect of fat (or moisture) × aging × holding time interaction, and ε_{ijkl} = residual variation. The statistical model employed for data from LMPS Mozzarella cheese was:

$$Y_{jkl} = \mu + A_j + T_k + (A \times T)_{jk} + \varepsilon_{jkl},$$

where Y = cheese meltability, μ = reference, A = effect of aging (j = 1 to 4), T = effect of holding time (k = 1 to 3), A × T = effect of aging × holding time interaction, and ε_{jkl} = residual variation. Significant interactions and main effects were compared using Fisher's Protected LSD. The interaction effect is described as significant only when $P < 0.05$.

RESULTS AND DISCUSSION

Preliminary Study

Effect of holding time and temperature on the meltability of 3-wk-old full fat Cheddar cheese is shown in Figure 1. There was no significant change in meltability of the samples during holding at 40 or 50°C. However, there was a general tendency toward decreased meltability during the first 20 min of holding at 60°C. Meltability of the samples from 20 to 40 min of holding were significantly lower than samples held for 10 min or less.

Based on these preliminary findings, a standard set of conditions (test temperature = 60°C, holding times = 0, 10, and 20 min) was defined and used in the studies described hereafter.

Cheddar Cheese

The mean values of the composition of Cheddar cheeses are presented in Table 1. The MNFP was similar between experimental lots differed in FDM and the experimental lots that differed in MNFP had fairly similar levels of FDM 7.72 to 12.7%. The decrease in pH values as the MNFP increased may confound the effect of MNFP on meltability.

The effects of holding time and aging on the meltability at 60°C of Cheddar cheeses different in FDM are shown in Figure 2. At 1 and 3 wk, the meltability of the traditional Cheddar cheese decreased with increasing

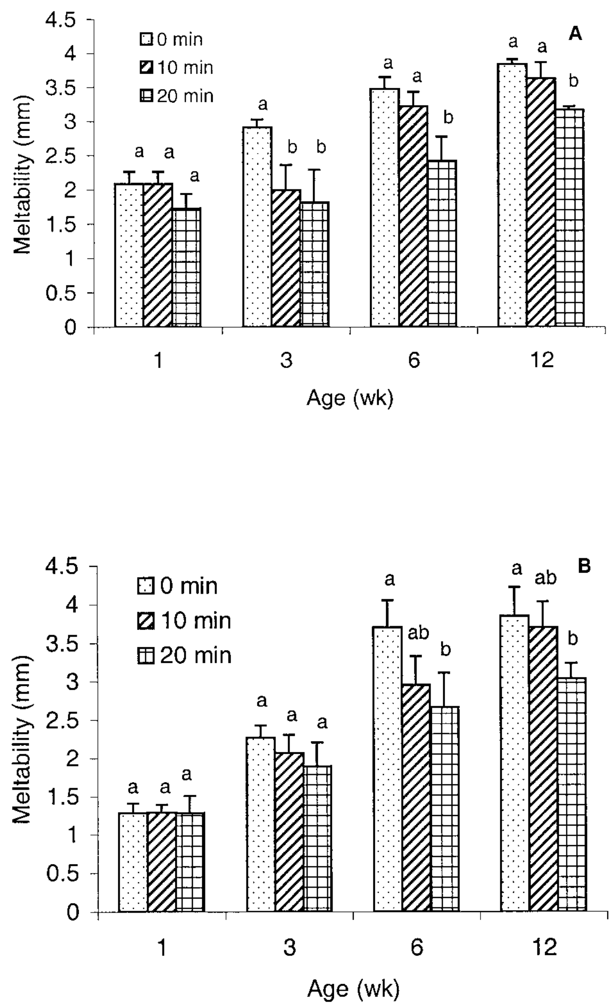

Figure 2. Effect of holding time at 60°C and age on the meltability of Cheddar cheese of two fat in DM (FDM) levels, (A) 52% FDM; (B) 36% FDM. The standard deviation is indicated on top of the bars. [a,b,c]Different letters indicate significance ($P < 0.05$) between the mean meltability values within each age.

holding time, but the change was significant ($P < 0.05$) for only the 3-wk-old cheese of normal fat content. At 6 and 12 wk, both cheeses, heated to 60°C for 20 min, showed a significant ($P < 0.05$) decrease in meltability.

As cheese is heated, the protein matrix adsorbs energy, which influences the interactions that maintain the protein structure (Meyers, 1990). Interactions under entropic control (e.g., hydrophobic interactions) are strengthened, while those under enthalpic control (i.e., electrostatic and van der Waals' interactions and hydrogen bonds) are weakened. As a result of the opposing temperature dependencies, unfolding of proteins occurs in the 60 to 80°C range. When proper hydrophobic sites are exposed due to unfolding, hydrophobic interactions are excited among the exposed hydrophobic sites resulting in the aggregation of the protein molecules (Nakai, 1983). Accordingly, we feel that when the cheeses were held long enough at appropriate temperature (60°C), the caseins aggregate, causing a decrease in cheese meltability.

Kim (1999) measured the surface hydrophobicity by the *cis*-parinaric acid fluororescence method and the solubility by the spectrophotometric Biuret method of 12-wk-old Cheddar cheese at 60°C as function of holding time. He showed that a significant increase of surface hydrophobicity was observed during the first 70 min. The solubility was negatively correlated to the hydrophobicity during heating (r = –0.966). He indicated that the increase in surface hydrophobicity and decrease in solubility of Cheddar cheese during heating resulted in the decrease of cheese meltability.

The effects of holding time and aging on the meltability of low fat Cheddar cheeses of three MNFP levels are shown in Figure 3. The very low meltability of the low MNFP cheese probably resulted from a combination of the high value protein content and low MNFP of this cheese. At 1 and 3 wk, the meltability of all cheeses was not statistically different as holding time increased. At 6 and 12 wk of aging, the meltability of all cheeses decreased with holding time increased up to 20 min at 60°C but only the cheeses with the high moisture content (57% MNFP) changed significantly ($P < 0.05$). It seems possible that prolonged heating of Cheddar cheeses up to 20 min at 60°C induced exposure of previously buried hydrophobic groups in protein matrix, resulting in enhanced hydrophobic interactions. The accumulated protein aggregation in casein matrix during heating changed the distribution of moisture within protein matrix. Local hardness and uneven distribution of moisture in protein matrix decreased the meltability of cheese.

Meltability increased as expected with aging (Figures 4a and 5a), due to structural modifications in the cheese during maturation (Tunick et al., 1993b). The casein matrix in cheese becomes softer and less elastic during storage due to the breakdown of α_{s1}-casein (Tunick et al., 1993a). The effect is more pronounced for reduced fat cheese as evidenced by the significant ($P < 0.05$) fat × aging interaction (Table 2) and for low fat cheese of high moisture content, leading to significant ($P < 0.05$) moisture × aging interactions (Table 3). An increase in MNFP increases the rate of proteolysis in cheese (Lawrence et al., 1984).

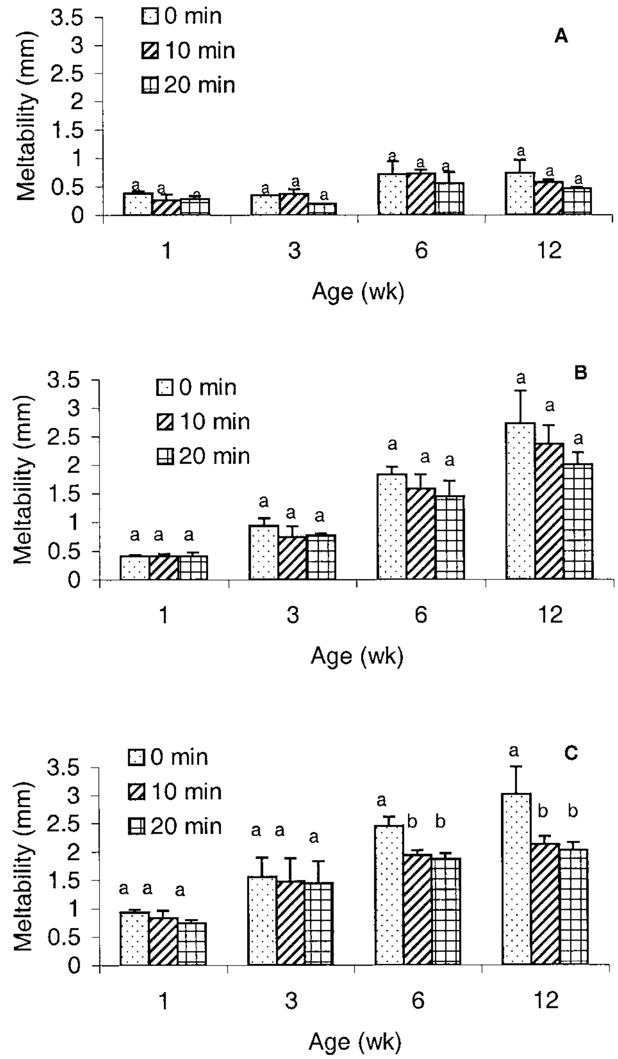

Figure 3. Effect of holding time at 60°C and age on the meltability of Cheddar cheese of three moisture in nonfat protein (MNFP) levels, (A) 46% MNFP; (B) 54% MNFP; (C) 57% MNFP. The standard deviation is indicated on top of the bars. [a,b,c]Different letters indicate significance ($P < 0.05$) between the mean meltability values within each age.

Statistical analyses show that the effect of holding time on cheese meltability was same whether the FDM or MNFP values of cheeses were low or high (Figure 4b and 5b), resulting in insignificant fat × holding time

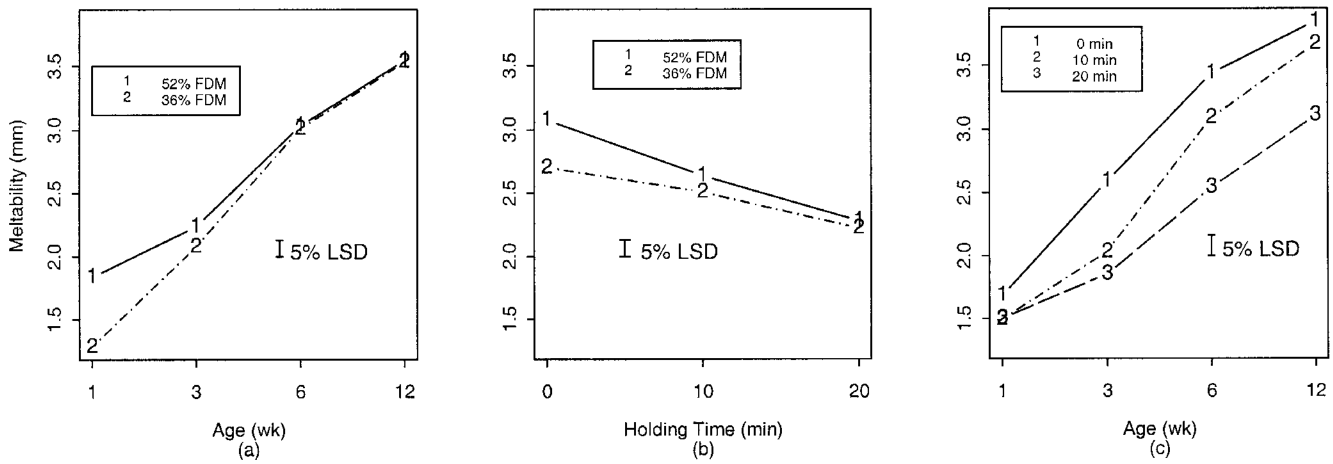

Figure 4. Interaction plots for Cheddar cheeses of different fat contents: (a) interaction plot of ageand fat in DM (FDM); (b) interaction plot of holding times and FDM; (c) interaction plot of age and holding times. LSD bar is based on full interaction model.

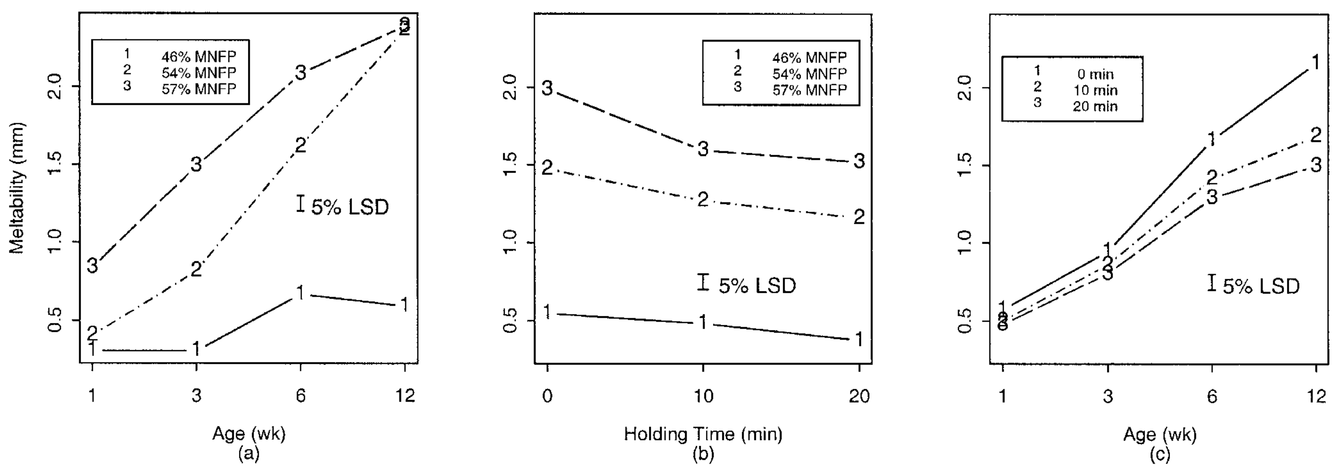

Figure 5. Interaction plots for Cheddar cheeses of different moisture contents: (a) interaction plot of age and moisture in nonfat protein (MNFP); (b) interaction plot of holding times and MNFP; (c) interaction plot of age and holding times. LSD bar is based on full interaction model.

Table 2. Effect of experimental variables on meltability-statistical analysis of Cheddar cheese of different fat in dry matter levels.

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F*-Value	*P*-Value
Fat (F)	1	0.638	0.638	8.68	0.0050
Aging (A)	3	41.896	13.965	189.91	0.0001
Holding time (T)	2	4.885	2.442	33.21	0.0001
F × A	3	0.860	0.287	3.90	0.0143
F × T	2	0.331	0.165	2.25	0.1165
A × T	6	1.259	0.210	2.85	0.0186
F × A × T	6	0.556	0.0927	1.26	0.2934
Error	48	3.530	0.074		
Total	71	53.954			

Table 3. Effect of experimental variables on meltability-statistical analysis of Cheddar cheese of different moisture in nonfat protein levels.

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F*-Value	*P*-Value
Moisture (M)	2	28.434	14.217	312.06	0.0001
Aging (A)	3	26.239	8.746	191.98	0.0001
Holding time (T)	2	1.914	0.957	21.01	0.0001
M × A	6	7.854	1.309	28.73	0.0001
M × T	4	0.394	0.099	2.16	0.0818
A × T	6	0.968	0.161	3.54	0.0040
M × A × T	12	0.492	0.041	0.90	0.5509
Error	72	3.280	0.046		
Total	107	69.575			

interactions (Table 2) and moisture × holding time interactions (Table 3). Therefore, the amounts of fat and moisture in cheese do not contribute to the effect of holding time on meltability.

The effect of holding time on cheese meltability was more pronounced at 6 and 12 wk of aging (Figure 4c and 5c), as evidenced by the significant ($P < 0.05$) aging × holding time interactions (Tables 2 and 3). Because the casein aggregates of young cheese crosslink throughout the cheese structure (Creamer et al., 1982), the hydrophobic groups are not readily exposed during heating, and thus the hydrophobic interactions are rather limited. However, due to proteolysis that breaks these network linkages, the protein matrix in mature cheese (at least 6 wk of aging) is fairly open. This allows hydrophobic bonding to form more readily as holding time is prolonged at high temperature.

The meltability of cheese containing 57% MNFP is higher than those of 46 and 54% MNFP (Figure 5a). Visser (1992) suggested that the lower the water content, the higher the protein concentration and the number of intermolecular bonds, the higher the compression modulus (stiffness). At high moisture levels, on the other hand, the lower protein concentration and the smaller number of intermolecular bonds, resulting in more freedom of the particles to move with each other, consequently the less viscous the cheese and the higher loss tangent.

LMPS Mozzarella Cheese

The effect of holding time and aging on the meltability of LMPS Mozzarella cheese at 60°C are shown in Figure 6. Meltability of LMPS Mozzarella cheese was affected significantly ($P < 0.05$) by the holding time. The results were consistent with those of Cheddar cheese.

The effect of holding time on the cheese meltability was almost the same at age 3, 6, and 12 wk, resulting in insignificant ($P < 0.05$) aging × holding time interactions (Table 4). The oriented structure of the protein matrix and hydrophobic interactions in Mozzarella cheese apparently caused a redistribution of moisture in casein matrix during heating at 60°C up to 20 min, hence decreased the meltability of cheese.

Cheddar cheese and Mozzarella cheese with similar FDM and MNFP exhibited similar meltabilities at 1 and 3 wk of age (Figures 2b and 6). The meltabilities of these cheeses also were not significantly affected by holding at 60°C. Meltabilities of Cheddar were higher than those of Mozzarella cheese at 6 and 12 wk of age, which probably resulted from greater degradation of casein in the Cheddar cheese. However, there appeared to be sufficient proteolysis in the Mozzarella cheese at 6 and 12 wk to induce the association of macropeptides and lower the meltability.

CONCLUSION

In both Cheddar and LMPS Mozzarella cheeses, meltability decreased with an increase in holding time from 0 to 20 min at 60°C with effect becoming significant

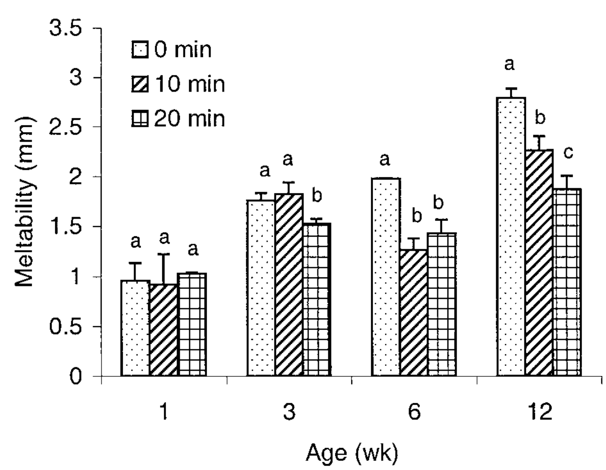

Figure 6. Effect of holding time at 60°C and age on the meltability of low moisture, part skim (LMPS) Mozzarella cheese. The standard deviation is indicated on top of the bars. [a,b,c]Different letters indicate significance ($P < 0.05$) between the mean meltability values within each age.

Table 4. Effect of experimental variables on meltability-statistical analysis of low moisture, part skim Mozzarella cheese.

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F*-Value	*P*-Value
Aging (A)	3	9.167	3.056	28.71	0.0001
Holding time (T)	2	1.617	0.808	7.59	0.0029
A × T	6	1.155	0.193	1.81	0.1416
Error	23	2.448	0.106		
Total	34	14.387			

after sufficient aging of the cheese. The effect of holding time on meltability was independent of cheese type and composition (fat and moisture). The meltability of young cheese was scarcely affected by holding time, in sharp contrast to the aged cheese, where increased holding time greatly reduced meltability. Results of this research suggest that a more complete understanding of the relationship between protein interactions and temperature history during heating could yield new insight into the relationship between structure and function, which could possibly lead to new strategies to improve the melting characteristics of cheeses.

REFERENCES

Ak, M. M., and S. Gunasekaran. 1995. Evaluating rheological properties of Mozzarella cheese by the squeezing flow method. J. Texture Stud. 26:695–711.

Arnott, D. R., H. A. Morris, and W. B. Combs. 1957. Effect of certain chemical factors on the melting quality of process cheese. J. Dairy Sci. 40:957–963.

Bogenrief, D. D., and N. F. Olson. 1995. Hydrolysis of beta-casein increases Cheddar cheese meltability. Milchwissenchaft 50:678–682.

Case, R. A., R. L. Bradley, Jr., and R. R. Williams. 1985. Chemical and physical methods. Page 327–404 *in* Standard Methods for the Examination of Dairy Products. G. H. Richardson. 15th ed. Am. Publ. Health Assoc., Inc., Washington, DC.

Creamer, L. K., H. F. Zoerb, N. F. Olson, and T. Richardson. 1982. Surface hydrophobicity of α_{S1}-I, α_{S1}-casein A and B and its implications in cheese structure. J. Dairy Sci. 65:902–906.

Gupta, S. K. 1972. Changes in the chemical and physical properties of the proteins in Cheddar and Gouda cheese during aging. Ph.D. Thesis, University of Illinois, Urbana-Champaign.

Hong, Y. H., J. J. Yun, D. M. Barbano, K. L. Larose, and P. S. Kindstedt. 1998. Mozzarella cheese: impact of three commercial culture strains on composition, proteolysis and functional properties. Aust. J. Dairy Technol. 53(3):163–169.

Johnson, M. E., and N. F. Olson. 1985. A comparison of available methods for determining salt levels in cheese. J. Dairy Sci. 68:1020–1024.

Kim, S. 1999. Physicochemical changes occurring in Cheddar cheese during heating. Ph.D. Thesis, University of Wisconsin, Madison.

Kindstedt, P. S., J. J. Yun, D. M. Barbano, and K. L. Larose. 1995. Mozzarella cheese: Impact of coagulant concentration on chemical composition, proteolysis and functional properties. J. Dairy Sci. 78:2591–2597.

Kuo, M.-I., Y.-C. Wang, and S. Gunasekaran. 1999. A viscoelasticity index for cheese meltability evaluation. J. Dairy Sci. 83:412–417.

Lawrence, R. C., H. A. Heap, and J. Gilles. 1984. A controlled approach to cheese technology. J. Dairy Sci. 67:1632.

Madsen, J. S., and K. B. Qvist. 1998. Mozzarella made by ultrafiltration. Australian J. Dairy Technol. 53(2):112.

Myers, C. D. 1990. Study of thermodynamics and kinetics of protein stability by thermal analysis. Page 16–50 *in* Thermal Analysis of Foods. V. R. Harwalkar and C.-Y. Ma, ed. Elsevier Appl. Sci., New York, NY.

Nakai, S. 1983. Structure-function relationships of food proteins with an emphasis on the importance of protein hydrophobicity. J. Agric. Food Chem. 31:676–683.

Tunick, M. H., K. L. Mackey, J. J. Shieh, P. W. Smith, P. Cooke, and E. L. Malin. 1993a. Rheology and microstructure of low-fat Mozzarella cheese. Int. Dairy J. 3:649–662.

Tunick, M. H., E. L. Malin, P. W. Smith, J. J. Shieh, B. C. Sullivan, K. L. Mackey, and V. H. Holsinger. 1993b. Proteolysis and rheology of low fat and full fat Mozzarella cheeses prepared from homogenized milk. J. Dairy Sci. 76:3621–3628.

Tunick, M. H., E. L. Malin, P. W. Smith, and V. H. Holsinger. 1995. Effect of skim milk homogenization on proteolysis and rheology of Mozzarella cheese. Int. Dairy J. 5:483–491.

Tunick, M. H., and J. J. Shieh. 1995. Rheology of reduced fat Mozzarella cheese. Pages 7–19 *in* Chemistry of Structure-Function Relationships in Cheese. E. L. Malin and M. H. Tunick, eds. Plenum Press, New York, NY.

Visser, J. 1992. Factors affecting the rheological and fracture properties of hard and semi-hard cheese. Pages 49–61 *in* Bull. 268. Int. Dairy Fed., Brussels, Belgium.

Wang, Y.-C., K. Muthukumarappan, M. M. Ak, and S. Gunasekaran. 1998. A device for evaluating melt/flow characteristics of cheeses. J. Texture Stud. 29:43–55.

Yun, J. J., D. M. Barbano, P. S. Kindstedt, and K. L. Larose. 1995a. Mozzarella cheese: impact of whey pH at draining on chemical composition, proteolysis, and functional properties. J. Dairy Sci. 78:1–7.

Yun, J. J., D. M. Barbano, L. J. Kiely, and P. S. Kindstedt. 1995b. Mozzarella cheese: impact of rod:coccus ratio on composition, proteolysis, and functional properties. J. Dairy Sci. 78:751–760.