Manufacture of Reduced Fat Mozzarella Cheese Using Ultrafiltered Sweet Buttermilk and Homogenized Cream[1]

V. S. PODUVAL[2] and V. V. MISTRY[3]
Minnesota-South Dakota Dairy Foods Research Center,
Dairy Science Department, South Dakota State University,
Brookings 57007-0647

ABSTRACT

Reduced fat Mozzarella cheese was manufactured from 0.5% fat milk that was standardized with unhomogenized or homogenized cream, from 0.5% fat milk with 3 or 5% ultrafiltered sweet buttermilk, or from ultrafiltered milk and homogenized cream. Curds were cheddared to a pH of 5.1 to 5.3, iced overnight, hand-stretched, brined for 10.5 h, vacuum-packaged, and stored at 4°C for 5 wk. The fat content in the cheeses ranged from 11.23 to 12.71%, and the moisture content ranged from 48.14 to 50.52%. The homogenization of the cream lowered the free oil content by 49%, and ultrafiltered buttermilk lowered it further. The percentage of free oil increased over time in all treatments. Homogenization of the cream did not affect the meltability of cheeses, but use of ultrafiltered buttermilk lowered meltability. Cheeses with 5% ultrafiltered buttermilk were the softest and had the highest scores for body and texture. Storage had no effect on hardness or on body and texture. Micrographs of cheeses from homogenized cream revealed many small fat globules. Cheeses with ultrafiltered buttermilk had a spongy and open protein matrix.
(**Key words**: Mozzarella cheese, sweet buttermilk, ultrafiltration)

Abbreviation key: **3BM** = 0.5% fat milk with 3% UBM and homogenized cream, **5BM** = 0.5% fat milk with 5% UBM and homogenized cream, **FOFB** = free oil on a fat basis, **HOC** = 0.5% fat milk standardized with homogenized cream, **TPA** = texture profile analysis, **UBM** = ultrafiltered sweet buttermilk, **UHC** = 0.5% fat milk standardized with unhomogenized cream, **UM** = ultrafiltered milk, **3UM** = 0.5% fat milk with 3% UM and homogenized cream, **5UM** = 0.5% fat milk with 5% UM and homogenized cream.

INTRODUCTION

Optimum body in cheese is attributed in part to the disruption of the continuity of the protein matrix by a large number of fat globules. The surface area of fat in reduced fat cheese may approach that in full fat cheese when fat globule size is reduced via homogenization. Homogenization of milk adversely affects protein structure and causes curd shattering, but homogenization of cream improves the body of reduced fat Cheddar cheese (19).

The reduction of fat in Mozzarella cheese adversely affects its functionality and quality. Process modification targeted at retaining moisture in the cheese and removing excess Ca has helped to alleviate some of these problems (18, 23). Removal of fat also lowers the amount of fat globule membrane, which contains surface-active agents and adversely affects cheese body and texture (22). Sweet buttermilk, a by-product of butter making, contains the fat globule membrane and may be useful for the manufacture of reduced fat cheese (22, 27). However, because of low TS in buttermilk, large quantities are needed to affect cheese quality. The concentration of TS can be selectively increased by UF, thus reducing the amount of buttermilk to be added (22). The objective of this research was to evaluate the effects of UF sweet buttermilk (**UBM**) and homogenized cream on the quality and functional properties of reduced fat Mozzarella cheese.

MATERIALS AND METHODS

Ultrafiltration

Sweet buttermilk. Approximately 910 kg of cream (40.25% fat) were pasteurized at 68.3°C for 30 min and were cooled to 4°C. Pasteurized cream (215 kg) was used to make butter in a batch churn (model A; General Dairy Equipment Co., Minneapolis, MN). After 50 min of churning, sweet buttermilk was

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[2]Present address: Marigold Foods, Inc., 420 W. Broadway Avenue, Minneapolis, MN 55411.
[3]Reprint requests.

drained and was stored in 38-L stainless steel cans at 4°C. Sweet buttermilk from four batches of butter making was pooled and UF at 54°C to a volumetric concentration ratio of 5:1 using a pilot UF unit equipped with a 5.6-m^2 spiral wound membrane (model 1/1; Koch Membrane Systems Inc., Wilmington, MA). The concentrate was cooled to 15°C and was stored in 11-kg plastic containers at –20°C.

Milk. Raw whole milk (3.25%) was separated at 4°C (DeLaval Separator Co., New York, NY), standardized with cream to 0.62% fat (equal to that in the sweet buttermilk), pasteurized (62.8°C for 30 min), and UF to a volumetric concentration ratio of 5:1. The UF milk (**UM**) was stored as described for sweet buttermilk.

Milk Processing

Six treatments were employed: 0.5% fat milk standardized with unhomogenized cream (**UHC**; the control), 0.5% fat milk standardized with homogenized cream (**HOC**), 0.5% fat milk with 3% UBM and homogenized cream (**3BM**), 0.5% fat milk with 5% UBM and homogenized cream (**5BM**), 0.5% fat milk with 3% UM and homogenized cream (**3UM**), and 0.5% fat milk with 5% UM and homogenized cream (**5UM**).

Whole milk (550 kg) was separated at 4°C (DeLaval Separator Co.) to 0.5% fat milk and cream containing approximately 40% fat. Part of the cream was homogenized at 55°C in a Gaulin two-stage homogenizer (Haskon Inc., St. Paul, MN) with first- and second-stage pressures of 17.25 and 3.43 MPa, respectively. Homogenized cream was added to the 0.5% fat milk, and the mixture was pasteurized (62.8°C for 30 min) immediately for the five treatments that required homogenized cream. Cream for UHC was added to the 0.5% fat milk without homogenization, and the mixture was pasteurized (62.8°C for 30 min) separately. Milks were stored at 4°C until used. The UBM and UM were warmed to 25°C and were added to the cheese vats at the time of cheese making.

Cheese Making

Milks (56.7 kg) were randomly allotted to two 250-kg cheese vats (4 MX model 65; Kusel Equipment Co., Watertown, WI) and were heated to 32°C. Six vats of cheese were made over 3 d. Either UBM or UM was added depending upon treatment. Frozen, concentrated direct-to-vat set starter culture containing *Streptococcus thermophilus* and *Lactobacillus delbrukeii* ssp. *bulgaricus* (1:1, wt/wt; TC120 and TR160; Rhône-Poulenc Dairy Ingredients, Madison, WI) was added at the rate of 20 g/100 kg of milk, followed by 22.5 ml of $CaCl_2$ (Rhône-Poulenc Dairy Ingredients). After a ripening period of 30 min, single-strength rennet extract (Rhône-Poulenc Dairy Ingredients) was added at 20 ml/100 kg of milk. The rennet curd was cut using 0.64-cm wire knives. After healing for 15 min, the curds containing UBM were cooked to a final temperature of 43°C over a period of 45 min, and the other curds were cooked to a final temperature of 39°C over the same time period. The whey was drained, and the curd was cheddared to a pH of 5.1 to 5.3; most lots had pH values of 5.25 to 5.28. Curd blocks were turned every 20 min during cheddaring. The curd was milled into cubes (2 cm × 2 cm × 1.5 cm) with a knife and iced overnight. The next morning, the curd was hand-stretched multidirectionally; approximately 300 g of cheese were immersed in hot water (80 to 90°C) for 6 min, stretched eight times, immersed in hot water for another 6 min, and stretched eight more times. The stretched curd was molded into a ball, salt-brined (23% NaCl and 0.07% Ca) for 10.5 h, vacuum-packaged in Cryovac bags (Cryovac Division; W. R. Grace and Co., Duncan, SC) using a Multivac® vacuum-packaging machine (Koch Inc., Kansas City, MO), and stored at 4°C for 5 wk. Low moisture, part-skim Mozzarella cheeses manufactured in a commercial plant at the same time were stored under the same conditions and were used as references for some of the tests.

Analysis

Two balls of reduced fat cheese from each batch were shredded completely and were used for all analyses of composition, free oil, and meltability.

Composition. For sweet buttermilk, milk, and cheese, total protein was determined with the macro-Kjeldahl method (2) and for fat by the Mojonnier method (2, 3). The TS in the sweet buttermilk, skim milk, and milk used for cheese was determined by the Mojonnier method (2), and the moisture content of the cheese was determined with a moisture balance (model MB200; Ohaus Corp., Florham Park, NJ) (4). Ash content was determined by heating in a muffle furnace at 535°C (2). The salt content of the cheese was determined using a sodium electrode attached to an ion analyzer (model 150; Corning Medical, Medfield, MA) (11).

Free oil. Free oil in cheese was determined at 1, 3, and 5 wk (12). The results were expressed as the percentage of free oil on a fat basis (**FOFB**) calculated as follows: free oil = measured fat column (percentage)/2, and FOFB = free oil/percentage of fat in cheese.

Meltability. The meltability of reduced fat Mozzarella cheese was determined at 1, 3, and 5 wk, using the procedure of Olson and Price (24) with modifications. Ten grams of shredded cheese were placed in a test tube (32 mm × 200 mm; Corning Products, Corning, NY) and were packed to form a plug at the bottom. The test tube was sealed with a number 6 rubber stopper. A hole let the hot gas escape during heating. The test tube was placed vertically in a refrigerator at 4°C for 30 min and then horizontally in an oven and heated at 104°C for 100 min. The procedure was modified to increase the heating time in the oven from 60 to 100 min. Meltability is generally reduced when fat is removed from the cheese, and so higher temperatures or longer times are required to obtain sufficient melting for a comparative study. Meltability was measured in centimeters from the bottom of the test tube to the point at which the cheese had stopped flowing.

Hardness. Texture profile analysis (**TPA**) of cheese hardness was determined at 1, 3, and 5 wk using a two-bite test to 75% compression (26, 36). Cylindrical samples (2-cm diameter × 2-cm height) were cut, and force-distance curves were obtained with a Sintech texture instrument (model 2/D; MTS Sintech Inc., Research Triangle Park, NC) using a 45.4-kg load cell and a crosshead speed of 50 mm/min. The highest force in kilograms during the first compression was TPA hardness.

Sensory evaluation. A panel of three judges that were experienced in evaluating cheeses evaluated the control, experimental, and reference cheeses at 1, 3, and 5 wk for appearance, flavor, and body and texture on an 11-point scale (0 = poor to 10 = excellent) (13). The order of grading the cheese samples was randomized each time, and cheeses were maintained at 4 to 5°C prior to evaluation.

Microstructure. The cheese microstructure was evaluated at 1 and 5 wk using scanning electron microscopy (1, 21). Samples were viewed using a scanning electron microscope (ISI Super III A; Top-Con Technologies Inc., Pleasanton, CA) operated at 15kV. Photomicrographs were taken at magnifications of 350, 750, 1500, and 3000× (Type 55 Polaroid® 50 ASA film; Polaroid Corp., Cambridge, MA). Scanning electron microscopic evaluations were made on two replicates of all cheeses, including the reference cheese. Micrographs were taken in several locations on each sample, and those shown here demonstrate representative characteristics of each treatment.

Statistical analysis. Five replicates of reduced fat Mozzarella cheese were manufactured (30 vats). The reference cheeses were obtained from a commercial plant from 5 different manufacturing. The manufacturing day of each reference cheese coincided with the manufacturing day of each replicate. The experiment was set up as a factorial design, and all data were analyzed as a randomized complete block design. Compositional data for the milk used for cheese making and for the resultant cheese were analyzed using the ANOVA procedure of SAS (28), and differences between means were determined using least significant difference (28). The general linear model of SAS was used for FOFB and meltability [six treatments × three ages (weeks)], TPA hardness [seven treatments (including reference cheese) × three ages (weeks)], and sensory evaluation [seven treatments (including reference) × three ages (week) × three panelists]. Significance was determined by least square means for PROC GLM.

RESULTS AND DISCUSSION

Composition of Ultrafiltered Products

Sweet buttermilk, pooled from the four batches of butter making, had 0.63% fat, 2.82% total protein, and 9.00% TS (Table 1). With UF to approximately 5:1 volumetric concentration, fat and protein increased to 3.42 and 13.78%, respectively. Percentages

TABLE 1. Composition of products before and after ultrafiltration.

Component	Buttermilk[1]	UBM[2]	Milk	UM
Fat, %	0.63	3.42	0.62	3.36
Total protein, %	2.82	13.78	3.20	16.52
Ash, %	0.60	1.45	0.73	1.82
TS, %	9.00	23.52	9.57	26.59
Casein[3]:fat	3.49	3.14	4.03	3.84

[1]Mean of four batches of sweet buttermilk.

[2]UBM = UF sweet buttermilk; UM = UF milk.

[3]Casein = Total protein × 0.78.

TABLE 2. Composition[1] of milks used for cheese making.

	Treatment[2]						
Component	UHC	HOC	3BM	5BM	3UM	5UM	LSD
Fat, %	1.08[e]	1.09[e]	1.17[d]	1.21[b]	1.19[c]	1.25[a]	0.014
Total protein, %	3.33[d]	3.27[d]	3.57[c]	3.74[b]	3.59[c]	3.88[a]	0.086
Ash, %	0.71[c]	0.70[c]	0.71[c]	0.73[b]	0.73[b]	0.76[a]	0.017
TS, %	10.26[d]	10.15[d]	10.51[c]	10.72[b]	10.60[c]	10.96[a]	0.117
Casein[3]:fat	2.41[a]	2.35[c]	2.39[ab]	2.42[a]	2.36[bc]	2.43[a]	0.043

[a,b,c,d,e]Means within a row with no common superscript differ ($P < 0.05$).

[1]Mean of five replicate batches.

[2]Treatment: UHC = 0.5% fat milk standardized with unhomogenized cream, HOC = 0.5% fat milk standardized with homogenized cream, 3BM = 0.5% fat milk with 3% UF sweet buttermilk and homogenized cream, 5BM = 0.5% fat milk with 5% UF sweet buttermilk and homogenized cream, 3UM = 0.5% fat milk with 3% UF milk and homogenized cream, and 5UM = 0.5% fat milk with 5% UF milk and homogenized cream.

[3]Casein = Total protein × 0.78.

of fat and total protein in the 0.62% fat milk increased to 3.36 and 16.52%, respectively.

Composition of Cheese Milk

The desired ratio of casein to fat was 2.40. As this ratio was high in UBM (Table 1), additional cream was required for 3BM and 5BM to obtain a ratio similar to that in the UHC and HOC. Consequently, the fat, protein, and TS of 3BM and 5BM were higher ($P < 0.05$) than those of UHC and HOC (Table 2). The purpose of treatments containing UM (3UM and 5UM) was to allow direct comparison between UBM and UM.

Fat and protein contents, respectively, were the lowest for UHC (1.08 and 3.33%) and HOC (1.09 and 3.27%) and were highest for 5UM (1.25 and 3.88%) (Table 2). Similarly, the TS content of control milks was lower than that of milks containing UBM and UM. There were no differences ($P > 0.05$) in the ratio of casein to fat in UHC, 3BM, 5BM, or 5UM.

Composition of Cheese

The fat content of reduced fat Mozzarella cheeses ranged from 11.23 to 12.71%, giving a 40 to 47% reduction in fat relative to the reference cheese (Table 3). The fat in DM was highest in cheeses made from HOC (24.85%) and was lowest in cheeses made from 5BM (22.71%). High fat losses in cheese made with buttermilk have been reported (15, 23). Homogenization of cream increased the fat in DM of

TABLE 3. Composition[1] of Mozzarella cheese.

	Treatment[2]							
Component	UHC	HOC	3BM	5BM	3UM	5UM	REF	LSD
	(%)							
Fat	12.31[bc]	12.71[b]	11.90[c]	11.23[d]	12.65[b]	12.44[b]	21.15[a]	0.462
Total protein	32.75[a]	32.07[bc]	31.70[cd]	31.38[d]	32.61[ab]	32.94[a]	25.47[e]	0.669
Ash	3.98[b]	3.98[b]	4.08[ab]	4.29[a]	4.02[ab]	4.03[ab]	2.80[c]	0.272
Salt	1.44[b]	1.48[b]	1.59[b]	1.93[a]	1.51[b]	1.41[b]	1.04[c]	0.256
Moisture	48.51[c]	48.85[bc]	49.90[ab]	50.52[a]	48.34[c]	48.14[c]	46.98[d]	1.111
FDM[3]	23.90[c]	24.85[b]	23.76[c]	22.71[d]	24.48[bc]	24.00[c]	39.91[a]	0.802
MNFS[4]	55.32[c]	55.96[bc]	56.64[b]	56.91[b]	55.34[c]	54.98[c]	59.58[a]	1.224

[a,b,c,d,e]Means within a row with no common superscript differ ($P < 0.05$).

[1]Mean of five replicate batches.

[2]Treatment: UHC = 0.5% fat milk standardized with unhomogenized cream, HOC = 0.5% fat milk standardized with homogenized cream, 3BM = 0.5% fat milk with 3% UF sweet buttermilk and homogenized cream, 5BM = 0.5% fat milk with 5% UF sweet buttermilk and homogenized cream, 3UM = 0.5% fat milk with 3% UF milk and homogenized cream, 5UM = 0.5% fat milk with 5% UF milk and homogenized cream, and REF = commercial reference low-moisture part-skim Mozzarella cheese.

[3]Fat in the DM.

[4]Moisture in the nonfat substance.

cheeses. In other studies, homogenized milk (5, 16) and homogenized cream (19) showed similar effects.

Even though higher cooking temperatures (43°C) were used for cheeses from 3BM and 5BM than for other cheeses (39°C), the cheeses from 3BM and 5BM had higher moisture (49.90 and 50.52%, respectively) (Table 3), probably because of reduced expulsion of whey (6, 15, 17, 22). Homogenization of cream had no impact ($P > 0.05$) on cheese moisture.

The protein content of the cheeses ranged from 31.38% (5BM) to 32.94% (5UM) (Table 3). The reference cheese had 25.47% protein. The salt content in cheeses from 5BM (1.93%) was higher ($P < 0.05$) than that of all other cheeses. The simultaneous increase in salt and moisture in cheeses from 5BM can be attributed to the change in curd structure caused by the addition of buttermilk (27).

Free Oil

The interaction of treatment with age (weeks) for FOFB was not significant ($P > 0.05$) (Table 4). Therefore, comparisons were made for treatment means averaged over 1, 3, and 5 wk and for age means averaged over the six treatments. Homogenization of cream reduced FOFB by 49% (8.8% for cheeses from UHC to 4.5% for cheeses from HOC) (Table 5). Addition of UBM reduced it further, but addition of UM did not, suggesting that sweet buttermilk, rather than an increase in solids by UF, had an influence on free oil in cheese. Homogenization decreases fat globule size and, consequently, increases the surface area of fat (8), which improves the degree of emulsification (20, 31) and, consequently, lowers free oil formation (25). Reduction in FOFB by UBM could be due to the presence in sweet buttermilk of fat globule membrane, which is rich in phospholipids that may interact with proteins to improve emulsification and, thus, lower free oil.

Salt content of cheese is inversely related to FOFB (10), but the reduction in FOFB in this study was not a result of the higher salt content in cheeses from 5BM, because cheeses from 3BM also had lower FOFB, even though those cheeses had salt contents similar to those of cheeses from UHC and HOC. The FOFB increased ($P < 0.05$) during aging (Table 6). Refrigerated storage of Mozzarella cheese increased free oil because of proteolysis (31).

Meltability

As with free oil, the interaction of treatment with age was not significant ($P > 0.05$) for meltability (Table 4). Homogenization had no effect ($P > 0.05$) on meltability (i.e., meltability of cheeses made from UHC and HOC were similar), but the addition of UBM lowered ($P < 0.05$) meltability (Table 5). Furthermore, meltability decreased as the amount of UBM increased (7.1 cm for cheeses from 3BM and 6.5 cm for those from 5BM). The meltability of cheeses from HOC was similar ($P > 0.05$) to the meltability of cheeses from 3UM and 5UM.

The presence of fat globule membrane, which may form crosslinks with protein, may increase the extent of the crosslinks already formed in milk because of homogenization (8). This process, as well as water binding, may have affected the meltability of UBM cheeses. The heating temperature used for the meltability test (104°C) was much higher than the melting point of milk fatty acids. Therefore, the fatty acids of buttermilk, which have lower melting points (38), probably did not influence meltability.

A study of Halloumi cheese demonstrated that the addition of soybean lecithin incorporated by homogenization with recombined cream increased the meltability of cheese (14). This increase was attributed to the lecithin, which acted as a surface film and prevented casein micelles from forming part of the membrane on homogenized fat globules. It is conceivable that the addition of UBM during the homogenization of cream may prevent the inclusion of casein on the homogenized globules because of the availability of additional fat globule membrane from UBM (14) and may prevent the decrease in meltability with UBM. Meltability increased ($P < 0.05$) from 1 wk (7.1 cm) to 3 wk (7.7 cm) (Table 6), possibly because of proteolysis during storage (33).

Hardness

The interaction of treatment with age for TPA hardness was not significant ($P > 0.05$) (Table 4). Comparisons were made for treatment means averaged over 1, 3, and 5 wk and for age means averaged

TABLE 4. Analysis of variance for functionality of Mozzarella cheese.

Source of variation	*F* value		
	FOFB[1]	Meltability	Hardness
Treatment (T)	72.37*	33.44*	32.79*
Age (A), wk	36.45*	11.24*	0.56^{NS2}
T × A	0.44^{NS}	1.08^{NS}	0.40^{NS}

[1]Free oil on a fat basis.

[2]$P > 0.05$.

*$P \leq 0.05$.

TABLE 5. Effect of treatment on functionality[1] of reduced fat Mozzarella cheese.

	Treatment[2]							
Attribute	UHC	HOC	3BM	5BM	3UM	5UM	REF	LSD
FOFB,[3] %	8.8[a]	4.5[b]	3.9[c]	3.8[c]	4.8[b]	4.7[b]	ND[4]	0.604
Meltability, cm	8.2[a]	8.0[ab]	7.1[c]	6.5[d]	7.9[ab]	7.7[b]	ND	0.324
Hardness, kg	27.6[bc]	28.0[b]	26.0[bc]	24.9[c]	28.0[b]	32.1[a]	11.7[d]	NA[5]

[a,b,c,d]Means within a row with no common superscript differ ($P < 0.05$).

[1]Mean of five replicate batches.

[2]Treatment: UHC = 0.5% fat milk standardized with unhomogenized cream, HOC = 0.5% fat milk standardized with homogenized cream, 3BM = 0.5% fat milk with 3% UF sweet buttermilk and homogenized cream, 5BM = 0.5% fat milk with 5% UF sweet buttermilk and homogenized cream, 3UM = 0.5% fat milk with 3% UF milk and homogenized cream, 5UM = 0.5% fat milk with 5% UF milk and homogenized cream, and REF = commercial reference low moisture, part-skim Mozzarella cheese.

[3]Free oil on a fat basis.

[4]Not determined.

[5]Not available; unbalanced data set (missing values).

over the treatments and the reference cheese. The TPA hardness was highest ($P < 0.05$) for cheeses from 5UM (32.1 kg) (Table 5). Homogenization of cream did not influence TPA hardness, unlike the results of other studies (5, 16, 19) that either used homogenized milk instead of cream or used cheeses other than Mozzarella, which was evident from the sensory panel as well. The lower hardness in cheese from homogenized milk in the other studies could be due in part to higher moisture relative to the nonfat substance of those cheeses.

Cheeses from 5BM had lower ($P < 0.05$) TPA hardness than did all other cheeses except those from UHC and 3BM (Table 5). Body and texture scores of cheeses from 5BM were higher than those of other cheeses. Differences in TPA hardness between cheeses from 5BM and those from UHC and 3BM were significant ($P < 0.085$). This lower hardness can be partly attributed to the higher moisture content of cheeses from 5BM or could also be a direct effect of UBM as for reduced fat Cheddar cheese (22).

Cheeses from 5UM were the hardest ($P < 0.05$), and the reference low moisture, part-skim Mozzarella cheese was the softest ($P < 0.05$). The latter effect was primarily because the reference cheese had 73% more fat than the other cheeses.

The TPA hardness of cheeses was similar ($P > 0.05$) during storage (Table 6). Other studies (32, 34) have reported decreased hardness during refrigerated storage because proteolytic hydrolysis of the protein matrix made the cheese softer. Tunick and Shieh (35) reported a minimal decrease in hardness of Mozzarella cheese that had a low percentage of moisture in the nonfat substance, as did the cheeses in the present study.

Microstructure

The microstructure of cheeses from UHC at 1 wk (Figure 1a) showed a dense fibrous protein matrix interspersed with irregular smooth surfaced cavities or voids of different sizes. These cavities result from removal of fat and possibly serum during sample

TABLE 6. Effect of age on functionality[1] of reduced fat Mozzarella cheese.

	Age			
Attribute	1 wk	3 wk	5 wk	LSD
FOFB,[2] %	4.0[c]	5.3[b]	6.0[a]	NA[3]
Meltability, cm	7.1[b]	7.7[a]	7.9[a]	0.420
Hardness, kg	24.90[a]	25.70[a]	25.90[a]	ND[4]

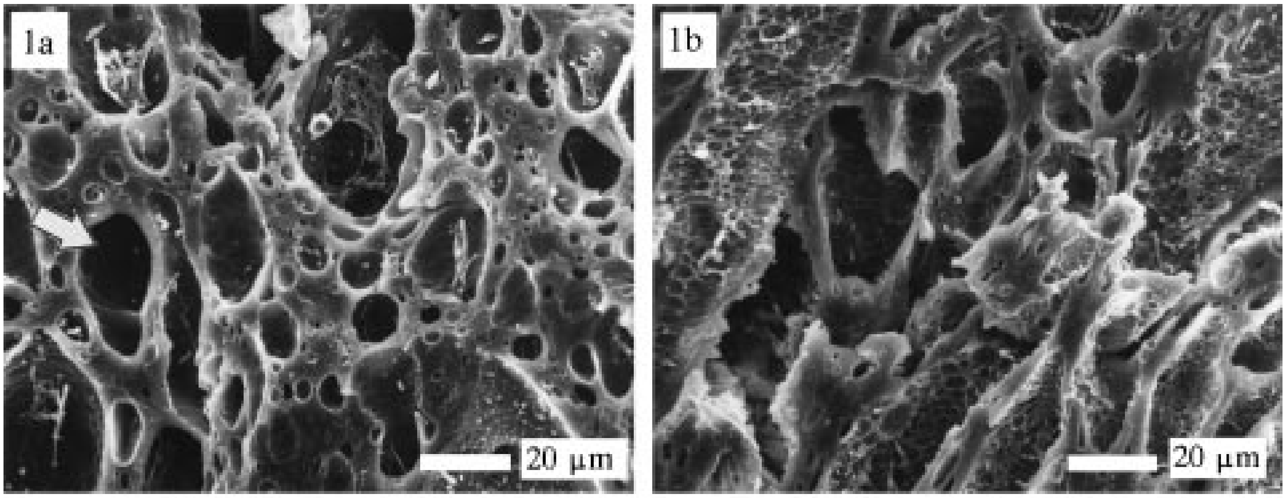
[a,b,c]Means within a row with no common superscript differ ($P < 0.05$).

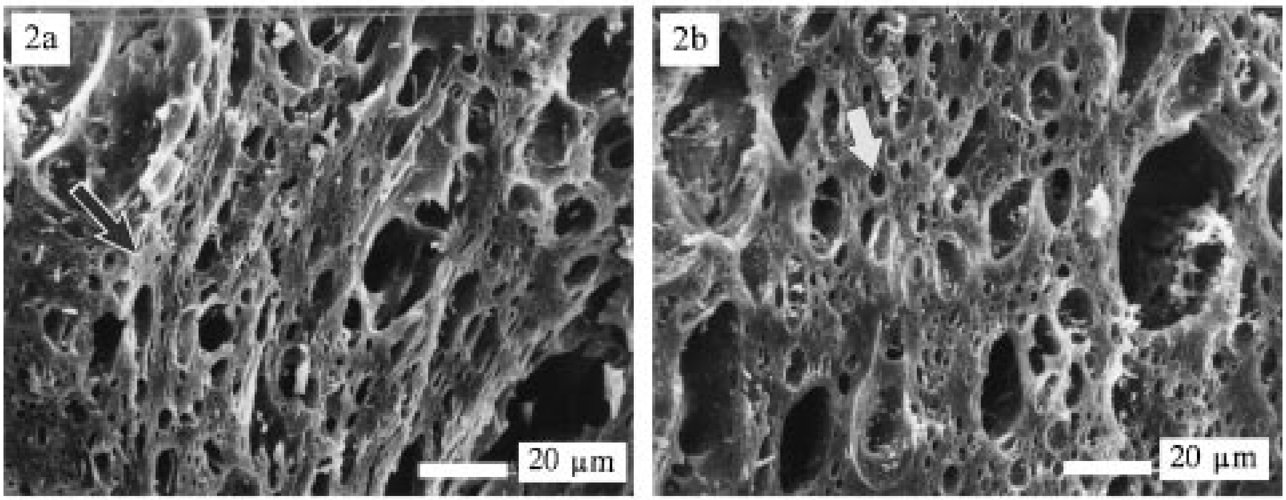
[1]Mean of five replicate batches averaged over treatments.

[2]Free oil on a fat basis.

[3]Not available; unbalanced data set (missing values).

[4]No differences ($P > 0.05$) in scores at 1 3, and 5 wk of age.





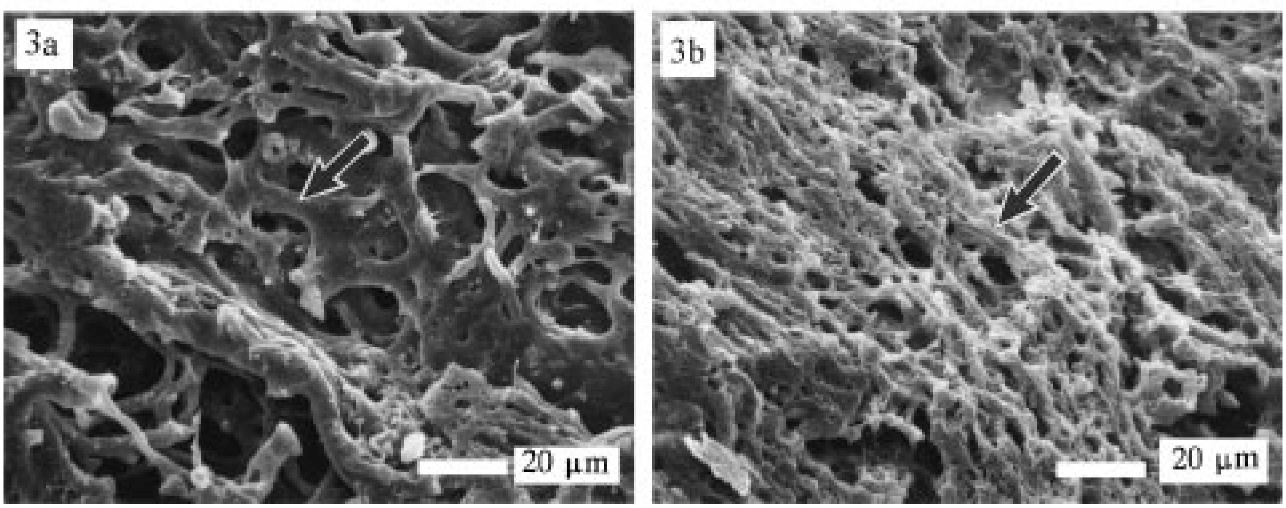


Figure 1. Scanning electron micrographs of Mozzarella cheeses from UHC (0.5% fat milk standardized with unhomogenized cream) at 1 wk (a) or 5 wk (b) of age. Large and irregular cavities indicate fat or serum pockets (white arrow).

Figure 2. Scanning electron micrographs of Mozzarella cheeses from HOC (0.5% fat milk standardized with homogenized cream) at 1 wk (a) and 5 wk (b) of age. Elongated protein matrix (black arrow) is an indication of stretching. Cavities (white arrow) are smaller and greater in number compared with cheese from UHC (Figure 1).

Figure 3. Scanning electron micrographs of Mozzarella cheeses from 3BM (0.5% fat milk with 3% ultrafiltered sweet buttermilk and homogenized cream) at 1 wk of age (a) and 5BM (0.5% fat milk with 5% UF sweet buttermilk and homogenized cream) at 1 wk of age (b). Black arrows indicate a spongy protein matrix.

preparation. The microstructure after 5 wk of storage (Figure 1b) showed larger cavities as aggregated spherical spaces that are irregular in size and shape in addition to the small cavities present in the cheese at 1 wk. Earlier studies have also indicated a similar transformation of irregular, smooth-surfaced cavities to fusiform areas consisting of aggregated spherical spaces during aging (32); this transformation may be caused by enzymatic activity during storage, which results in increased porosity of the protein matrix and allows the aggregation of lipids (9). An increase in size of the cavities may also occur because of weakening of the paracasein matrix caused by proteolysis or CO_2 production by starter or nonstarter bacteria (9).

Cheese from homogenized cream (Figure 2a) had a large number of small, irregularly shaped cavities. The smaller and larger numbers of fat globules reflects the increased emulsification (20, 29), which in turn may lower free oil formation in these cheeses. There were also a few large, irregularly shaped cavities. The elongated fibrous matrix is an indication of stretching (7, 30). As in cheeses from UHC, the cavities in cheeses from HOC also enlarged during storage (Figure 2b) but not to the same extent.

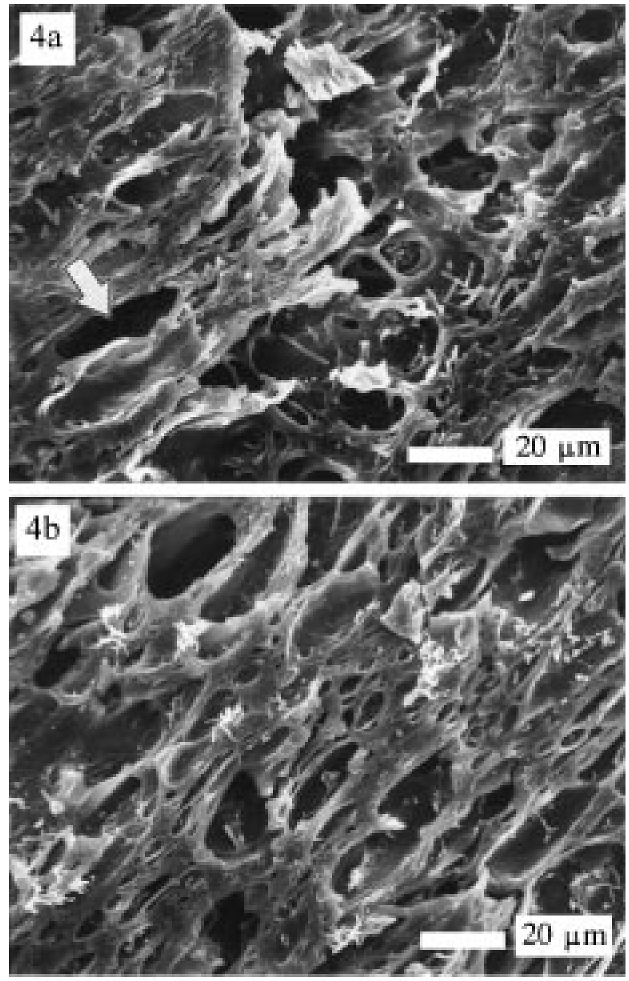
Cheeses from 3BM and 5BM had many small but irregularly shaped smooth cavities amidst a dense fibrous protein structure (Figure 3). Unlike all other cheeses (Figures 1, 2, 4, and 5), these cheeses had a spongy and open protein matrix without a sharp and definite orientation. The protein matrix had fibrous strands terminating in a bulblike formation. Age had no effect on the microstructure of these cheeses.

Cheeses from 3UM and 5UM (Figure 4) had a dense, fibrous protein matrix with a large number of small dispersed fat globules, which were similar to those in cheeses from HOC (Figure 2). Some large, irregular, smooth-surfaced cavities existed between the protein strands.

The reference low moisture, part-skim Mozzarella cheese had 72% more fat than did cheese from UHC. The reference cheese also had a fibrous protein matrix with a parallel orientation. Storage of the reference cheese resulted in aggregation of lipids into large spherical spaces, likely because of hydrolysis of casein matrix that holds the fat globules (32).

CONCLUSIONS

Two methods, the homogenization of cream and the use of UBM (3 and 5%), both of which independently improved quality of reduced fat Cheddar cheese, were combined to determine their effects on the quality of reduced fat Mozzarella cheese. Homogenization of cream lowered free oil, and UBM lowered it further,



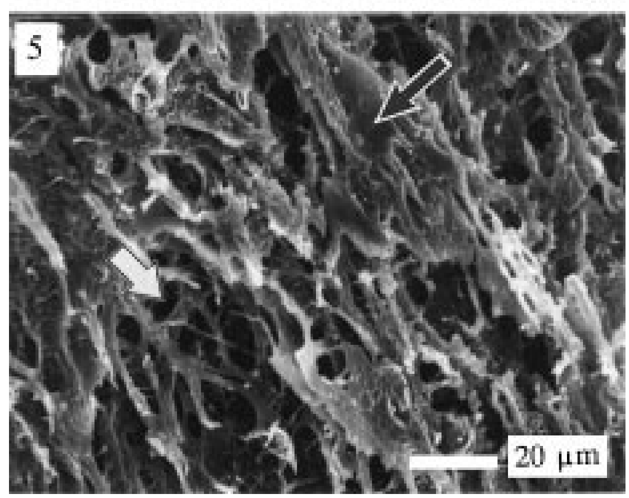


Figure 4. Scanning electron micrographs of Mozzarella cheeses from 3UM (0.5% fat milk with 3% UF milk and homogenized cream) at 1 wk of age (a) and 5UM (0.5% fat milk with 5% UF milk and homogenized cream) at 1 wk of age (b). White arrow indicates cavities.

Figure 5. Scanning electron micrographs of a reference low moisture, part-skim Mozzarella cheese at 1 wk of age. Elongated protein matrix (black arrow) with cavities (white arrow) of various sizes and shapes is visible.

but UM had no effect. The impact of reduction on free oil on scorching of the experimental cheeses in this study during baking needs to be studied. Homogenization of cream and UM had no effect on the meltability of cheese, but UBM lowered meltability. Because cheeses made with UF sweet buttermilk had a lower degree of melting at each age, UBM could conceivably be used to manipulate the degree of melting. In cheeses that have been stored longer, meltability normally increases because of proteolysis. Here also, UBM may offer possibilities of control. Cheeses made with 5% UBM were softer and had better body and texture relative to other cheeses except the commercial reference sample. Scanning electron micrographs of cheeses made with HOC showed fat globules that were smaller and more numerous than those made from UHC. Cheeses made with UBM had a spongy and open protein matrix. The changes in functional properties on addition of UBM but not UM indicate that these changes were caused as a result of sweet buttermilk rather than by compositional differences caused by the addition of UF products.

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