Use of Dry Milk Protein Concentrate in Pizza Cheese Manufactured by Culture or Direct Acidification

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ABSTRACT

Milk protein concentrate (MPC) contains high concentrations of casein and calcium and low concentrations of lactose. Enrichment of cheese milk with MPC should, therefore, enhance yields and improve quality. The objectives of this study were: 1) to compare pizza cheese made by culture acidification using standardized whole milk (WM) plus skim milk (SM) versus WM plus MPC; and 2) compare cheese made using WM + MPC by culture acidification to that made by direct acidification. The experimental design is as follows: vat 1 = WM + SM + culture (commercial thermophilic lactic acid bacteria), vat 2 = WM + MPC + culture, and vat 3 = WM + MPC + direct acid (2% citric acid). Each cheese milk was standardized to a protein-to-fat ratio of ~1.4. The experiment was repeated three times. Yield and composition of cheeses were determined by standard methods, whereas the proteolysis was assessed by urea polyacrylamide gel electrophoresis (PAGE) and water-soluble N contents. Meltability of the cheeses was determined during 1 mo of storage, in addition to pizza making. The addition of MPC improved the yields from $10.34 \pm 0.57\%$ in vat 1 cheese to $14.50 \pm 0.84\%$ and $16.65 \pm 2.23\%$, respectively, in vats 2 and 3 and cheeses. The percentage of fat and protein recoveries showed insignificant differences between the treatments, but TS recoveries were in the order, vat 2 > vat 3 > vat 1. Most of the compositional parameters were significantly affected by the different treatments. Vat 2 cheese had the highest calcium and lowest lactose concentrations. Vat 3 cheese had the best meltability. Vat 1 cheese initially had better meltability than vat 2 cheese; however, the difference became insignificant after 28 d of storage at 4°C. Vat 3 cheese had the softest texture and produced large-sized blisters when baked on pizza. The lowest and highest levels of proteolysis were found in vats 2 and 3 cheeses, respectively. The study demonstrates the

use of MPC in pizza cheese manufacture with improved yield both by culture acidification as well as direct acidification.

(**Key words:** pizza cheese, milk protein concentrate, acidification)

Abbreviation key: MPC = milk protein concentrate, NFDM = nonfat dry milk, SM = skim milk, WM = whole milk.

INTRODUCTION

Mozzarella cheese, a pasta-filata variety, constituted ~32.4% of the total cheese produced in the United States in 2001 (USDA, 2002). About 70% of the Mozzarella cheese produced in the United States is used in pizza manufacture and falls into the low-moisture, part-skim category, with a fat content of 30 to 45% on DM basis and moisture content of 45 to 52% (McMahon, et al., 1993). Mozzarella-type cheese not manufactured by the pasta-filata process is called pizza cheese. There has been a sharp increase in the consumption of pizza worldwide, resulting in high demand for Mozzarella or pizza cheese. Pizza cheese is an irreplaceable cheese for pizza because of its stretchability—the ability to form fibers or strings when hot.

To meet the moisture and fat requirements for low-moisture, part-skim Mozzarella, cheese milk is standardized to a desired protein-to-fat ratio of 1.4:1. This is equivalent to a casein-to-fat ratio of ~1.2:1, assuming casein represents 78% of the total protein in milk. The casein-to-fat ratio in normal bovine milk is between 0.64 to 0.72, depending on breed of cow. To increase the casein-to-fat ratio in cheese milk, nonfat dry milk (NFDM), condensed skim, or membrane concentrated skim milk are used in standardization of milk. Alternatively, some of the fat in whole milk can be removed as cream. The standardization of cheese milk by addition of solids in the form of NFDM, condensed skim does not only increase cheese yield, but also reduces the amount of whey. Demott (1982) manufactured Mozzarella-type cheese from NFDM by direct acidification method. The source of solids for cheese milk present some disadvantages. For example, the

Received February 28, 2003.

Accepted May 5, 2003.

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addition of NFDM or condensed skim may result undesirable fermentations during manufacture or extensive browning when cheese is used as a pizza topping due to its high lactose content compared with high solids ultrafiltration and diafiltered retentate.

Milk protein concentrate (**MPC**), manufactured by spray drying of ultrafiltration retentate, has high concentrations of casein and calcium and low concentrations of lactose compared to NFDM. Enrichment of whole milk with MPC should, therefore, enhance yields and improve quality of cheese. Milk protein concentrate has been used in France and Denmark for the manufacture of Camembert, Feta, and Ricotta type cheeses (Pederson and Ottosen, 1992). The use of liquid and dry MPC in the manufacture of reduced-fat Cheddar cheeses has been reported (Shakeel-Ur-Rehman et al., 2003a, 2003b).

The objectives of this study were 1) to compare pizza cheese made by culture acidification using whole milk (**WM**) standardized with skim milk versus WM standardized with MPC; 2) compare cheese made with WM plus MPC by culture acidification to that made by direct acidification.

MATERIALS AND METHODS

Cheese Manufacture

Three vats of pizza cheese were manufactured on three occasions (three trials). Vat 1 contained standardized milk consisting of 21.8 kg of skim milk (**SM**) plus 103.2 kg of WM and commercial thermophilic lactic acid bacteria. Standardized milk for vats 2 and 3 contained WM and MPC. Target protein-to-fat ratio in the standardized milk was 1.4. Milk protein concentrate was obtained from Main Street Ingredients (La Crosse, WI). It contained 63.5% protein, 20.9% lactose, 5% moisture, 3.1% fat, and 7.5% ash. Milk protein concentrate (4.925 kg) and raw WM (245 kg) were mixed in a tank before pasteurization. Each lot of standardized milk (~125 kg) was pasteurized at 72°C × 16 s using a universal pilot plant (PMS, Processing Machine and Supply Co., Philadelphia, PA) with a capacity to process 1.9 L of milk per minute. The pasteurized milk was cooled to 36°C for vats 1 and 2 and 4°C for vat 3. The beginning and end of each standardized milk (~10 kg) exiting the heat exchanger was discarded, and 100 kg was poured in the vat for cheese-making. The percentage of TS in vats 1, 2, and 3 were 11.42, 13.44, and 13.44, respectively. Frozen direct-vat set thermophilic starter culture obtained from Chr. Hansen's Inc., (Milwaukee, WI) was added to vats 1 or 2 at the rate of 6.6 g (3.3 g of *Lactobacillus bulgaricus*, ssp. *bulgaricus* LB12, and 3.3 g of *Streptococcus thermophilus*, STC5) per 100 kg of milk at 36°C. After

the addition of starter, the contents of vats 1 and 2 were held for 45 min to ripen. Then, rennet (Chymax, Chr Hansen's Inc.) was added (7 ml/100 kg of milk) to each vat, followed by 2 min of stirring. The vat contents were held undisturbed until a firm coagulum formed (~30 min). The coagulum was cut with 1-cm horizontal and vertical curd wire knives. The cut curds were heated for 2 to 3 min before slow stirring for 10 min. The curds were cooked to 46°C over 30 min with gentle stirring until the curd pH (measured by inserting pH electrode directly into a sample of squeezed curd) reached 6.2 in 30 to 40 min. The curds were allowed to settle in whey and the curd/whey mixture held under quiescent conditions until the pH reached to 5.3. The whey was drained followed by stretching of curds in hot water (82.3°C). It took ~2 to 3 h from cutting to stretching. The stretched molten cheese was placed in a 2.5-kg hoop to form a loaf. After removal from the hoop, the cheese was placed in cold (3°C) brine (20% NaCl + 0.01% CaCl₂, pH 4.6) for 12 h. The cheese blocks were taken out from the brine and vacuum packaged in Cryovac bags.

Vat 3 milk previously cooled to 4°C was directly acidified with 2% cold (3°C) citric acid to a pH of 5.6. Citric acid was selected because it is a strong chelator of calcium. After the addition of citric acid, the temperature of milk in the vat was increased to 31°C followed by the addition of chymosin (Chymax, Chr. Hansen's Laboratory, Milwaukee, WI) at the rate of 5 ml/100 kg of milk. It took ~5 min for coagulum formation. The curd was cut with horizontal wire knives like vats 1 and 2. The cut curd was heated for 5 min and then the temperature of the contents of the vat was increased to 36°C followed by stirring for 5 min. The whey was drained in 30 min. The curds were stretched, brine salted, and vacuum packaged as was done for cheese obtained from vats 1 and 2. All the cheeses were transferred to a storage room at 4°C and kept for 4 wk.

Yield

The yield of cheese was determined by weighing the cheese obtained in each vat after removal from the brine, and expressed as a percentage of the milk weight in the respective vat.

Compositional Analyses

Fat in milk and cheese was analyzed by the Babcock method (Marshall, 1992). Total solids in milk and moisture in cheese were determined by the microwave oven method (CEM AVC 80 microwave oven, CEM Corporation, Matthews, NC) (Marshall, 1992). Protein (total N × 6.38) was determined by the Kjeldahl

method, salt by titration using the Corning 926 Chloride analyzer (Corning, Medfield, MA), and lactose and β -galactose by enzymatic methods (Boehringer-Mannheim Biochemicals, Mannheim, Germany). Cheese pH was determined using a glass electrode on a slurry prepared by thoroughly blending 10 g of grated cheese with 10 ml of deionized water using a mortar and pestle. Calcium in the cheese was determined by AOAC method 991.25 (AOAC, 2002) by using Perkin-Elmer 3030B Atomic Absorption spectrophotometer (Norwalk, CT).

Functional Properties

Meltability (cheese flow) of the cheeses was measured by using the method of Olson and Price (1958) on 15-g sample cut out of a block with a small circular cutter. The sample was placed in a cylindrical glass tube (23.3-cm long $\times$ 3.0-cm i.d.), open on both ends. The end in which the sample was placed was closed by rubber cork. The tube containing the cheese sample was placed on a stainless steel rack having the provision of holding the tube in the horizontal or at a 45° inclined position. The rack was set at the inclined position in an incubator at 32°C for 1 h to temper the cheese, after which the rack was set on the horizontal position in an oven at 110°C for 1 h. The meltability of the sample was measured as the distance (cm) that the cheese had flowed from the original position after the tempering period.

The baking property of the cheese was determined by evenly distributing cheese (200 g) over a commercial pizza crust (27.5 cm diameter) containing pizza sauce (90 g) followed by baking in continuous Impinger oven (model 1301 Lincoln, Wayne, IN) at 232°C for 3.25 min. The conveyor speed was 0.33 rpm.

Hardness

A modified method of Bhaskaracharya and Shah (2000) was used to assess hardness of 7-d-old cheeses. The cheese blocks were tempered 25°C for 1 h and triplicate cylindrical samples (2.5 cm height $\times$ 3.0 cm diameter) from each block were drawn with a cheese plug. Cheese hardness, defined as the force required to compress 50 or 70% height of sample, was determined by a TAXT2 Texture analyzer (Texture Technologies Corporation, Scarsdale, NY) using a 500 N load cell with a flat plunger.

Proteolysis

Samples of cheese were taken after 7, 21, and 28 d of storage and frozen at -20°C until analyzed for

proteolysis. Water-soluble fractions of the cheeses were prepared according to the method of Kuchroo and Fox (1982), and the extract was analyzed for N by the Kjeldahl method. Primary proteolysis was assessed by performing urea-PAGE of the cheeses and by determining water-soluble N as percentage of total N. Total free amino acids (an index of secondary proteolysis) were determined by method of Folkerstma and Fox (1992).

Statistical Analysis

The data collected were statistically analyzed by ANOVA (one way and general linear model) using Min-itab statistical software package for Windows 98 (Min-itab Inc, State College, PA).

RESULTS AND DISCUSSION

Composition of Milk

The standardized milk for vats 2 and 3 had significantly higher fat, protein, and TS contents than those for vat 1 (Table 1).

Cheese Yield

The yield of pizza cheese made by culture acidification from WM plus SM (vat 1) was 10.34% compared with 14.51% in that made from WM plus MPC mixture (vat 2) (Table 2), suggesting that standardization of whole milk by MPC results in higher cheese yields. The yield of cheese made from standardized milk (WM + MPC) by direct acidification (vat 3) was 16.65% compared with 14.51% for that made by culture acidification (vat 2). The higher yield obtained in vat 3 than in vat 2 was due to the higher moisture content in vat 3 cheese than in the vat 2 cheese (Table 3). The 50% moisture adjusted yields were 11.19, 15.37, and 15.45% in vats 1, 2, and 3 cheeses, respectively.

The percentage of fat and protein recoveries among vats were insignificant; however, significant differences ($P < 0.01$) were observed in the TS recoveries (Table 1). The cheeses made from standardized milk containing MPC had significantly higher TS recoveries than those made from WM plus SM. Demott (1982) reported an average fat recovery of 84.31% in Mozzarella cheese manufactured by direct acidification from fluid milk or from reconstituted NFDM and cream but found that protein and TS recoveries in cheese made from NFDM plus cream by direct acidification were higher than in that made from fluid milk.

Composition of Cheese

Except for protein, the concentrations of all the other cheese components were significantly different be-

Table 1. Composition¹ ($\pm$ SD) of standardized milk used for pizza cheese manufacture.

Vat ²	Fat (%)	Protein (%)	Total solids (%)
1	2.70 $\pm$ 0.30	3.77 $\pm$ 0.38	11.42 $\pm$ 0.21
2	3.60 $\pm$ 0.60	5.08 $\pm$ 0.59	13.44 $\pm$ 0.29
3	3.60 $\pm$ 0.08	5.02 $\pm$ 0.53	13.44 $\pm$ 0.29
<i>P</i> -value	0.005	0.001	0.000

¹Mean of three trials analyzed in duplicate.

²Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification.

tween vats 1, 2, and 3 (Table 3). The calcium content was significantly higher in the culture-acidified cheeses made from WM plus MPC than that made from WM plus SM, suggesting that addition of MPC to WM results in higher calcium content in the resultant pizza cheese. The higher calcium content in the MPC containing cheese is good from the nutritional point of view but resulted in lower meltability during storage (Figure 1). The cheese made by using direct acidification from WM plus MPC had the lowest calcium concentration and best initial melt. The reduction in the calcium contents in cheese made by direct acidification technique is due to lower pH of the standardized milk. As the pH of standardized milk is reduced, colloidal calcium gets converted to soluble calcium and subsequently gets lost in whey (Kiely et al., 1992). The reduction in calcium contents by direct acidification are in agreement with those of Joshi et al. (2002) who lowered the calcium content of part-skim Mozzarella cheese by preacidifying milk with citric acid.

Pizza cheese made by culture acidification of WM plus MPC had lower lactose content than that made from WM plus SM. The reduced lactose content will help to minimize the browning defect during baking of cheese on pizza. The cheese made by direct acidification technique had 0.53% lactose compared to 0.33 and 0.32%, respectively, in the cheeses made by culture acidification from WM plus SM and from WM plus MPC. The utilization of lactose by culture microorgan-

isms during manufacture resulted in lower lactose contents in the cheeses made by culture acidification compared with the cheese made by direct acidification technique. The concentration of β -galactose (a byproduct of lactose fermentation by *S. thermophilus*) was minimum in the cheese manufactured by direct acidification. The cheese made by culture acidification technique from MPC plus WM had slightly lower β -galactose content than that made from WM plus SM, suggesting faster activity of starter bacteria in the cheese made from WM plus SM compared with that made from MPC plus WM. The high protein content in vat 2 cheese due to addition of MPC resulted in higher buffering capacity compared with vat 1, hence, lower finished pH in vat 1 than in vat 2 cheeses.

Functional Properties

The pizza cheese made by direct acidification had significantly ($P < 0.00$) higher meltability (Figure 1) during the first 21 d of storage. However, after 28 d of storage, the differences in meltability due to treatment became insignificant ($P > 0.25$). The initial high meltability value of cheese made by direct acidification (vat 3) compared with that made by culture acidification is due to its high moisture and low calcium contents (Table 3) and also its high degree of primary proteolysis (Figures 2 and 3) compared with vats 1 and 2 cheeses. Joshi et al. (2002) reported that lowering the

Table 2. Percent¹ yields and fat, protein, and total solid recoveries during pizza cheese manufacture.

Vat ²	Actual yield	50% Moisture-adjusted yield	Fat recovery (%)	Protein recovery (%)	Total solids recovery (%) ³
1	10.34	11.19	78.19	64.13	44.30
2	14.51	15.37	86.29	61.52	55.68
3	16.65	15.45	77.07	58.44	53.49
SEM	0.29	0.28	1.96	2.30	1.10
<i>P</i> -value	0.00	0.00	0.146	0.611	0.002

¹Mean of three trials analyzed in duplicate.

²Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification.

³After subtracting salt contents from the cheeses.

Table 3. Composition¹ of 7-d-old pizza cheeses.²

Vat ³	Moisture (%)	FDM ⁴ (%)	Protein (%)	Salt (%)	Ca (mg/100 g)	Lactose (%)	β -Galactose (%)	pH
1	46.18 ($\pm$ 1.50)	37.92 ($\pm$ 1.49)	22.59 ($\pm$ 2.16)	1.42 ($\pm$ 0.50)	534.1 ($\pm$ 0.01)	0.33 ($\pm$ 0.01)	0.14 ($\pm$ 0.02)	5.38 ($\pm$ 0.02)
2	47.18 ($\pm$ 1.17)	38.64 ($\pm$ 2.15)	23.70 ($\pm$ 1.19)	2.22 ($\pm$ 0.46)	590.0 ($\pm$ 0.01)	0.32 ($\pm$ 0.00)	0.13 ($\pm$ 0.01)	5.47 ($\pm$ 0.05)
3	53.87 ($\pm$ 2.79)	34.68 ($\pm$ 1.54)	23.37 ($\pm$ 2.26)	2.04 ($\pm$ 0.44)	342.5 ($\pm$ 0.01)	0.53 ($\pm$ 0.01)	0.01 ($\pm$ 0.01)	5.59 ($\pm$ 0.02)
<i>p</i> -value	0.000	0.001	0.605	0.025	0.009	0.033	0.000	0.000

¹Mean of three trials analyzed in duplicate.

²Numbers in the parenthesis are standard deviations.

³Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification.

⁴Fat in DM.

concentration of micellar calcium by preacidification of milk increased melt area of salted and unsalted part-skim Mozzarella cheese. Upadhyay et al. (1986) reported that Mozzarella cheese made from buffalo milk by direct acidification had higher meltability compared with that made using starter culture.

Seven-day-old vats 1 and 2 cheeses had similar rates of meltability, but after 21 d vat 1 had better meltability, probably due to slightly faster proteolysis in vat 1 compared with vat 2 cheese. Also vat 2 cheese had significantly ($P < 0.05$) higher levels of calcium compared with vat 1 cheese, which may also have contributed to reduced meltability of vat 2 cheese. Paulson et al. (1998) reported that high calcium in cheese results in aggregation of casein, thus more energy is required to disrupt the protein matrix, which leads to poor melting. The meltability progressively increased during storage in the culture-acidified cheeses. Kuo et al. (2001) reported that meltability of cheeses increased

during aging due to structural modifications in the cheese during maturation. The meltability of cheese made by direct acidification remained nearly constant during the storage period. The similarities in meltability of cheeses after 28 d may be due to increases in proteolysis during storage. Joshi et al. (2002) reported that increased proteolysis during storage had a greater influence on melting property than calcium content of cheese.

Little or no browning plus large-sized blisters (Table 4) were observed when vat 3 cheeses were baked on pizza, whereas moderate browning and very small-sized blisters were noted on vat 1 and extensive brown-

Figure 1. Meltability* (cm) during storage of pizza cheeses heated at 110°C for 60 min. Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification. *Mean of three trials analyzed in duplicate.

Figure 2. Urea-polyacrylamide gel electrophoresis of pizza cheeses. Lane 1 is sodium caseinate, lanes 2 to 4 are 7-d-old cheeses obtained from vats 1, 2, and 3, respectively; lanes 5 to 7 are 28-d-old vat 1, 2, and 3 cheeses. Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification.

Figure 3. Water-soluble* N (as percentage of total N) content during storage of pizza cheese. Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification. *Mean of three trials analyzed in duplicate.

ing and medium-sized blisters in vat 2 cheeses. The little or moderate browning in vat 3 cheeses may be due to reduced concentration of amino acids (secondary proteolysis) (Table 5), although vat 3 cheeses had the highest level of primary proteolysis (Figures 2 and 3). The browning of baked Mozzarella cheese is a result of residual lactose or galactose in the cheese undergoing Maillard browning reaction with peptides and amino acids (Johnson and Olson, 1985). The cheese made by culture acidification contained significantly higher galactose content than that made by direct acidification. Both lactose and galactose are reducing sugars and can react with amino groups and can cause browning. Oberg et al. (1991) reported that Mozzarella cheese made by direct acidification remained white after baking compared with that made with starter cultures and did not brown even though there was considerable amount of residual lactose. The large size blisters observed during the baking of vat 3 cheeses on pizza is due to higher moisture contents (Table 3) in vat 3 cheese compared with vats 1 and 2 cheeses. The blisters in Mozzarella cheese are formed when it is heated to temperatures above 100°C. The moisture at surface or below the cheese is converted to steam

and the trapped air between the molten cheese and toppings collect in bubbles under the molten surface. Next the cheese surface over these bubbles begins to rise from the expansion of trapped air and steam, initiating the formation of a blister (Rudan and Barbano, 1998).

Proteolysis

Urea-PAGE of the cheeses (Figure 2) and their water-soluble N contents (Figure 3) showed that vat 3 cheeses had higher levels of proteolysis compared with vats 1 and 2 cheeses. The higher level of proteolysis found in vat 3 cheeses may be due to lower (36°C) curd cooking temperature used during the manufacture of vat 3 cheeses compared with cooking temperature of 46°C in vats 1 and 3 cheeses. Yun et al. (1993) used three cooking temperatures (38, 41, and 44°C) during the manufacture of Mozzarella cheese and found that as cooking temperature increased, proteolysis decreased. Chymosin is inactivated at temperatures >45°C (Fox and McSweeney, 1997). Also, because of the low pH at setting, the level of coagulant retained was high as residual coagulant increases with the pH of the milk at clotting decreases (Farkye, 1995). Ernstrom (1987) reported that more coagulant gets attached with cheese curd when manufactured from preacidified milk and results in higher proteolysis. Vat 3 cheese had lower calcium compared with vats 1 and 2.

Joshi et al. (2002) reported that rate of proteolysis in cheeses containing low concentrations of Ca was higher than in cheese containing high levels of calcium. Dave et al. (2003) reported that residual chymosin and plasmin are responsible for breaking down α_{s1} -CN and β -CN in Mozzarella cheese (made by direct acidification) during storage. Plasmin has been reported to cause initial hydrolysis of β -CN (and α_{s1} -CN) due to its greater specificity towards β -CN, when chymosin is used as a coagulant (Benfeldt et al., 1997). Plasmin inhibitors get inactivated at temperatures be-

Table 4. Baking properties in pizza oven at 232°C for 3.25 min.

Vat ¹	Browning	Size of blisters
1	Moderate	0.5 mm diameter
2	Extensive	1.0 mm diameter
3	Little to moderate	2.0 mm diameter

¹Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification.

Table 5. Concentration¹ ($\pm$ SD) of free amino acids (mg Leu/g of cheese) during storage of pizza cheese.

Vat ²	Age of cheese (days)		
	7	21	28
1	0.310 $\pm$ 0.030	0.354 $\pm$ 0.002	0.484 $\pm$ 0.001
2	0.296 $\pm$ 0.030	0.395 $\pm$ 0.001	0.451 $\pm$ 0.025
3	0.230 $\pm$ 0.050	0.300 $\pm$ 0.003	0.316 $\pm$ 0.005
P-value	0.008	0.000	0.000

¹Mean of three trials analyzed in triplicate.

²Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification.

Table 6. Force (g) required to compress 50 or 70% height of 7-d-old pizza cheese sample.

Vat ¹	50% Compression	70% Compression
1	4229 ± 607	6638 ± 334
2	6818 ± 979	14773 ± 1286
3	930 ± 13.5	3941 ± 132

¹Vat 1 = whole milk plus skim milk; culture acidification; vat 2 = whole milk plus milk protein concentrate; culture acidification; vat 3 = whole milk plus milk protein concentrate; direct acidification.

tween 63 to 90°C, whereas plasmin is a relatively heat stable enzyme. Farkye et al. (1991) reported that considerable proteolysis in Mozzarella cheese occurs in 14 d of refrigerated storage, soluble N increases from 4% of total N to 10% after 14 d. The concentration of free amino acids was higher in the culture acidified cheeses compared with those made by direct acidification (Table 5), probably due to activities of starter peptidases.

Hardness

The force required to compress 50 or 70% height of 7-d-old cheese samples showed that vats 3 and 2 cheeses had the softest body texture and hardest textures, respectively (Table 6). The soft texture in vat 3 cheese may be due to more moisture, less calcium, and higher level of proteolysis compared with vats 2 and 3 cheese. These results are in agreement with those of Metzger et al. (2001) who reported the least hardness in low-fat Mozzarella cheese due to preacidification of milk. Vat 2 cheese had the highest calcium content, making it possibly the hardest cheese. Bhaskaracharya and Shah (1999) reported that increase in moisture content of Mozzarella cheese resulted in decreased hardness.

CONCLUSIONS

The use of MPC in pizza cheese manufacture increased yields regardless of whether cheese was made by culture or direct acidification. Also, the use of MPC resulted in increased calcium content in the cheeses made by culture acidification but low calcium in cheeses made by direct acidification. Cheeses made by direct acidification gave high melt and minimum browning when used for pizza baking immediately after manufacture and during storage. Pizza cheese made from MPC and by culture acidification improved meltability during storage. A *Lactobacillus helveticus* strain capable of readily fermenting galactose may be included in the starter culture if pizza cheese from MPC with minimum browning is to be obtained.

ACKNOWLEDGMENTS

The financial support of Dairy Management, Inc. and California Dairy Research Foundation is greatly acknowledged. The help of Therese Considine, Jerry Mattas in cheese making, and that of Sean Vink in texture analysis is appreciated.

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