DAIRY FOODS RESEARCH PAPERS

Microstructure and Meltability of Model Process Cheese Made with Rennet and Acid Casein

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ABSTRACT

Process cheese models were prepared by blending acid or rennet casein, milk fat, sodium chloride, 2.5% emulsifying salt, and water and heating to 80°C. Four emulsifying salts (trisodium citrate, disodium phosphate, tetrasodium pyrophosphate, or sodium aluminum phosphate) were used. Undenatured or heat-denatured whey protein was added at 1.5, 3.0, or 4.5%. Microstructure and meltability of the models were examined. Emulsifying salts affected the degree of emulsification and meltability of the samples. Rennet casein models prepared with tetrasodium pyrophosphate or disodium phosphate were highly emulsified and had poor meltability. Samples prepared with trisodium citrate or sodium aluminum phosphate were not as emulsified and melted well. Acid casein models prepared with disodium phosphate were highly emulsified and melted very well. The remaining acid casein models had very open structure and melted well. Meltability decreased as whey protein concentration increased in both acid and rennet casein models. The highest whey protein concentration in the rennet casein model produced fibrous structures around the fat globules. Addition of whey protein to acid casein models did not affect emulsification. A relationship was noted between the fat emulsion and meltability in rennet casein but not in acid casein models.

INTRODUCTION

Utilization of ultrafiltered skim milk or whole milk retentate in the manufacture of cheese was first proposed by Maubois and Mocquot (8). Process cheese has been manufactured from ultrafiltered milk retentate as a partial substitute for natural cheese. Process cheese made with more than 40% plain retentate or 60% protease enzyme-treated retentate solids produced a cheese with long-grained texture and decreased meltability (17).

Ernstrom et al. (3) prepared cheese curd for processing (CCP) (38% moisture) by vacuum evaporating a cultured, ultrafiltered whole milk retentate. The CCP was substituted for 80% of natural cheese in pasteurized process cheese and pasteurized process cheese food. The flavor of both products was good; the texture of the process cheese food was good but that of the process cheese was stiff.

Process cheese made from CCP prepared from ultrafiltered milk has poor meltability and a brittle texture. Poor meltability was not corrected by extensive proteolysis (to 65% soluble nitrogen) or by increasing the moisture in the process cheese (P. A. Savello, 1981, unpublished results, Utah State University).

The composition of CCP from ultrafiltered milk is similar to that of traditional Cheddar cheese with three exceptions: 1) it contains a higher concentration of milk serum proteins; 2) the glycomacropeptide portion of k-casein is retained in the CCP, whereas it is lost in whey during traditional cheese manufacture; and 3) the calcium content of CCP is higher than that of natural cheese (.88 vs. .70%) (3, 22).

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Lonergan (7) reported that the structure as well as calcium and phosphorus composition of casein micelles do not change during ultrafiltration and diafiltration. Thus, the textural properties of cheese prepared from ultrafiltered milk retentate cannot be attributed to casein micellar changes during ultrafiltration.

Functionalities of whole casein (i.e., isoelectric casein), rennet casein, and whey proteins in process cheese have not been extensively reported. Differences in the calcium content and composition of acid and rennet caseins and the presence of whey protein in CCP suggested that these constituents might cause the meltability defect noted in process cheese made from CCP. Most commercial imitation process cheese utilizes rennet casein rather than acid casein even though the latter is less expensive (11).

The purpose of this research was to design and evaluate model process cheese made from rennet or acid casein, milk fat, emulsifying salts, and various levels of whey proteins in an effort to identify the factors contributing to poor meltability of process cheese made from CCP.

MATERIALS AND METHODS

Preparation of Model Process Cheese

All process cheese was prepared in duplicate in 2-kg batches in a 3-kg capacity scraped-surface, batch cooker. The cheese was indirectly heated by a steam jacket surrounding the bowl.

The basic formulation included: 483 g rennet casein or 486 g lactic acid casein (New Zealand Milk Products, Inc., Petaluma, CA); 616 g milk fat; 50 g anhydrous emulsifying salt as trisodium citrate (CIT), disodium phosphate (DSP), sodium-aluminum phosphate (SALP) or tetrasodium pyrophosphate (TSPP); 35 g sodium chloride; and sufficient deionized water to give the desired moisture content in the final product.

All experimental samples were formulated to yield process cheese with 39 to 40% moisture, 20 to 22% protein, 52 to 54% fat-in-dry-matter, 4.5% salt-in-moisture, and 2.5% emulsifying salt.

Rennet Casein Cheese. Process cheese made with rennet casein was prepared by blending the dry ingredients with previously warmed (50°C) milk fat in the cooker, heating the mixture to 66°C, adding sufficient lactic acid diluted with water to adjust the pH to 5.65 to 5.75 while mixing for 4 min at 66°C, then heating to a final temperature of 82°C in approximately 4 min. The product was held at 82°C for 1 min prior to packaging. Rennet casein process cheeses were prepared using the four types of emulsifying salts.

Acid Casein Cheese. Process cheese made with acid casein was similarly prepared except that a measured amount (25 to 75 ml) of 5 N NaOH was added to 80% of the water content required by the formulation and blended with the dry ingredient-warm milk fat mixture (50°C) before heating to 66°C. Trisodium citrate was the emulsifying salt. The mix was blended at 66°C for 4 min to “condition” the acid casein at pH from 5.80 to 7.30 depending on the amount of 5 N NaOH added. The remaining 20% of water to be added was acidified with lactic acid and was used to reduce the final pH to 5.65 to 5.75. Cooking was as described.

Process cheese made with acid casein and the other three emulsifying salts was similarly prepared. Sixty-five milliliters of 5 N NaOH added to 80% of the water required by the formulation was used to “condition” the acid casein. Lactic acid addition and cooking procedures were performed as described.

Process Cheese with Added Whey Proteins. Experimental process cheese made with added whey proteins was prepared in similar fashion except that an equivalent amount of casein was withheld from the formulation in order to maintain constant protein and total solids in the cheese. Whey protein at 1.5, 3.0, or 4.5% of the final product was added in the form of freeze-dried whey protein after the full mixture was heated to 74°C. The cheese was then cooked to 82°C and held 1 min prior to packaging. All model process cheese samples were packaged in 454-kg round plastic containers and stored at 4°C until tested.

Undenatured Whey Protein

Eleven kilograms of whey protein concentrate (WPC) (Ward’s Cheese, Richfield, ID) were dissolved in 73 kg deionized water (5.4% whey protein). The solution was ultrafiltered at 25°C in an Abcor HFK-130 single-stage, spirai-

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wound, polysulfone membrane. Ultrafiltration was performed using 420 kPa inlet pressure and 280 kPa outlet pressure.

Dialfiltration with 225 kg deionized water added in nine 25-kg aliquots was performed to remove lactose and salts. Following dialfiltration, the solution was further ultrafiltered to one-fourth the original volume. The concentrated solution was frozen in stainless steel trays (29 x 42.5 x 4 cm) and freeze-dried in a Dura Dry Freeze Drier (FTS Systems, Inc., Stone Ridge, NY). The freeze-dried undenatured whey protein (UWP) was stored in plastic bags.

Denatured Whey Protein

Seven kilograms of WPC were dissolved in 243 kg deionized water (1% whey protein). The solution (pH 6.60) was heated to 85°C and held for 1 h (22). Following the heat treatment, the solution was cooled to 50°C, ultrafiltered, dialyzed with 625 kg deionized water, and concentrated to one-tenth the original solution volume. The denatured whey protein (DWP) solution was frozen, freeze-dried, and stored in plastic bags.

Chemical Analyses

**Moisture.** Cheese and ingredient moisture determinations were in duplicate by heating an accurately weighed sample (5 g) in an oven at 110°C for 16 h (14). Process cheese samples were finely graded (<1 mm³) prior to moisture analysis. Weight loss during heating was considered as water loss from the sample.

**Protein.** Nitrogen determinations on casein, WPC, UWP, DWP, and cheese were in duplicate by a semi-micro-Kjeldahl procedure (4). Protein was calculated as nitrogen × 6.38.

**Fat.** Fat in the process cheese was determined in duplicate by a modified Babcock method described by Van Slyke and Price (21).

**Soluble Protein at pH 4.40.** Soluble protein in the UWP and DWP and the process cheese samples was determined in duplicate according to a modification of the method of Vakaleris and Price (20). An accurately weighed 15.0-g sample of cheese was placed in a test tube. Forty milliliters of .5 N trisodium citrate solution (60°C) were added and the mixture blended. The entire cheese-citrate blend was transferred to a 200-ml volumetric flask and the solution brought to volume with deionized water. One hundred milliliters of the cheese-citrate blend was accurately measured and placed in a 250-ml Erlenmeyer flask. A measured volume of 1.47 N HCl was added to adjust the pH to 4.40 ± .05. The acidified blend was filtered through Whatman No. 42 filter paper. Ten milliliters of the filtrate was digested and the nitrogen content determined by a semi-micro-Kjeldahl procedure (4). Protein was calculated as nitrogen × 6.38.

**pH.** Eight grams of cheese was blended in 15 ml of deionized, glass-distilled water. The slurry pH was measured with an Orion pH/millivolt meter and a combination glass electrode. The slurry measurement was approximately .15 pH unit higher than measurement of undiluted cheese.

**Calcium.** Calcium in caseins, UWP, and DWP was determined in duplicate by atomic absorption spectrophotometry (1). A weighed (2.500 g) sample was ashed in a furnace at 550°C. The ash residue was dissolved in 5 ml of 6 N HCl and brought to 25 ml volume with 1000 ppm lanthanum oxide solution. The sample was diluted to bring the calcium concentration within the linear range of the spectrophotometer for calcium determination.

**Meltability.** Model process cheese samples were tested for meltability in triplicate by a modified meltability test described by Olson and Price (13). A cheese plug weighing 15.0 ± .1 g and measuring 30 mm in diameter and approximately 22 mm long was placed at one end of a Pyrex glass tube (30 mm inner diameter and 250 mm long). The cheese end of the tube was closed with a solid rubber stopper, and the opposite end was closed with a one-hole (3 mm) rubber stopper. A reference line indicating the leading edge of the cheese plug was drawn on the outside of the tube.

Melting tubes were placed in a stainless steel rack and incubated at 30°C for 120 min. During incubation, the melting tubes were placed on the rack at a 45° angle with the end containing the cheese plugs at the bottom. Following incubation, the melting tubes and rack were placed in a horizontal position in an oven at 110°C for 50 min. Flow of melted cheese within the tubes was halted upon removal from the oven by slightly tilting the rack from the horizontal. Distance of flow from the reference line to the leading edge of the melted cheese
The fragments were melted in absolute ethanol, mounted on SEM stubs, and coated with carbon and gold by vacuum evaporation. Specimens were examined under a Cambridge Stereoscan electron microscope operated at 20 kV (5).

Statistical Analysis. A randomized block experimental design was used in all meltability tests. Cheese samples were randomly placed in the melting rack slots. Each set of process cheese samples was randomized for the triplicate melting tests.

Analysis of variance determined the difference in meltability among the cheese samples. Where differences occurred among samples a Newman-Keul multiple range test (2) was used to determine significance between sample pairs.

RESULTS AND DISCUSSION

Casein and Whey Protein Composition

Acid and rennet caseins had moisture and protein levels of 10.5 vs. 10.9 and 90.4 vs. 84.2%, and calcium contents of 0 vs. 22.6 mg/g.

Acidification of skim milk to pH 4.6 to precipitate acid casein solubilizes the colloidal calcium associated with the caseinate micelles allowing it to drain out with the whey. No such loss of calcium occurs when rennet casein is prepared by enzymatic precipitation of the protein.

The UWP and DWP had similar moisture and protein levels (7.35 vs. 6.85 and 72.8 vs. 72.9%). These preparations contained very low levels of calcium (approximately 6 mg/g).

pH Conditioning of Acid Casein Process Cheese

Volumes of 5 N NaOH and 80% lactic acid added per kg of process cheese formulation made with CIT are recorded in Table 1. As the volume of NaOH was increased to condition the acid casein, lactic acid was increased to provide a uniform final pH in the product.

Table 2 records the volumes of 5 N NaOH and 80% lactic acid added to the formulations prepared with different emulsifying salts. Acid casein formulated with SALP, DSP, and TSPP required more lactic acid than the corresponding rennet casein formulation; less lactic acid was required in the acid casein than rennet casein cheese when CIT was used as the emulsifying salt.

Soluble Protein in Model Process Cheese

Cooking the process cheese with added UWP resulted in heat denaturation of some whey protein. The UWP contained 91.5% soluble

| Casein type | 5 N NaOH/kg Conditioning pH 80% Lactic acid/kg |
|-------------|------------------|------------------|------------------|
|             | (ml)             | (ml)             | (ml)             |
| Rennet      |                   |                  | 16.5             |
| Acid        | 12.5             | 5.80             |                  |
| Acid        | 17.5             | 6.05             | 3                |
| Acid        | 22.5             | 6.35             | 4.75             |
| Acid        | 27.5             | 6.70             | 7.5              |
| Acid        | 32.5             | 7.00             | 11               |
| Acid        | 37.5             | 7.30             | 15               |

1 Trisodium citrate (2.5%) used as emulsifying salt in all samples.

2 pH measured after addition of 5 N NaOH and blending for 4 min (prior to lactic acid solution).

3 Acid required to bring final product pH to 5.65 to 5.75.
nitrogen (pH 4.40) expressed as percent of total nitrogen in the freeze-dried powder. After cooking the cheese, only half of the whey protein nitrogen (from 38.6 to 50.4%) was soluble at pH 4.40 (Table 3). In contrast, there was no decrease in soluble nitrogen when cheese containing DWP was cooked. The heat treatment in preparing freeze-dried DWP resulted in 25.2% soluble nitrogen. All cheeses made with DWP contained this same percentage of soluble nitrogen (Table 3). Background soluble nitrogen values of acid and rennet casein process cheeses prepared with no added whey proteins were determined (.0478 and .0615 g N/100 g cheese). These background values were subtracted from soluble nitrogen values in cheeses containing whey protein.

Meltability of Model Process Cheese

Effect of pH Conditioning. The relationship between meltability of model process cheese and the type of casein is depicted in Figure 1. Rennet casein cheese melted significantly more than the acid casein cheese. Increasing the pH of the acid casein mixture by adding more NaOH before cooking helped solubilize the acid casein nitrogen mixture. 

### Table 2. Sodium hydroxide and lactic acid additions per kilogram of process cheese prepared with different emulsifying salts.

<table>
<thead>
<tr>
<th>Emulsifying salt</th>
<th>Casein type</th>
<th>5N NaOH/kg</th>
<th>Conditioning pH</th>
<th>80% Lactic acid/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALP Acid</td>
<td>32.5</td>
<td>7.65</td>
<td>18.5</td>
<td></td>
</tr>
<tr>
<td>DSP Acid</td>
<td>32.5</td>
<td>7.55</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>TSPP Acid</td>
<td>32.5</td>
<td>7.75</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>CIT Acid</td>
<td>32.5</td>
<td>6.95</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>SALP Rennet</td>
<td>...</td>
<td>...</td>
<td>12.5</td>
<td></td>
</tr>
<tr>
<td>DSP Rennet</td>
<td>...</td>
<td>...</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>TSPP Rennet</td>
<td>...</td>
<td>...</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>CIT Rennet</td>
<td>...</td>
<td>...</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

1. SALP = Sodium-aluminum phosphate, DSP = disodium phosphate, TSPP = tetrasodium pyrophosphate, and CIT = trisodium citrate.

2. pH measured after addition of 5 N NaOH and emulsifying salt followed by blending for 4 min at 66°C (prior to lactic acid solution).

3. Acid required to bring final product pH to 5.65 to 5.75.

### Table 3. Soluble protein in process cheese with added whey protein.

<table>
<thead>
<tr>
<th>Whey protein added</th>
<th>Casein type</th>
<th>Whey protein type</th>
<th>pH 4.4 Soluble protein as % total whey protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>(%)</td>
<td>(%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 Acid</td>
<td>UWP²</td>
<td>38.60</td>
<td></td>
</tr>
<tr>
<td>3.0 Acid</td>
<td>UWP</td>
<td>42.00</td>
<td></td>
</tr>
<tr>
<td>4.5 Acid</td>
<td>UWP</td>
<td>42.00</td>
<td></td>
</tr>
<tr>
<td>1.5 Rennet</td>
<td>UWP</td>
<td>49.90</td>
<td></td>
</tr>
<tr>
<td>3.0 Rennet</td>
<td>UWP</td>
<td>44.30</td>
<td></td>
</tr>
<tr>
<td>4.5 Rennet</td>
<td>UWP</td>
<td>50.40</td>
<td></td>
</tr>
<tr>
<td>1.5 Acid</td>
<td>DWP³</td>
<td>25.47</td>
<td></td>
</tr>
<tr>
<td>3.0 Acid</td>
<td>DWP</td>
<td>26.43</td>
<td></td>
</tr>
<tr>
<td>4.5 Acid</td>
<td>DWP</td>
<td>26.00</td>
<td></td>
</tr>
<tr>
<td>1.5 Rennet</td>
<td>DWP</td>
<td>27.00</td>
<td></td>
</tr>
<tr>
<td>3.0 Rennet</td>
<td>DWP</td>
<td>26.62</td>
<td></td>
</tr>
<tr>
<td>4.5 Rennet</td>
<td>DWP</td>
<td>24.00</td>
<td></td>
</tr>
</tbody>
</table>

1. Statistical analysis of duplicate determinations of duplicate samples.

2. Undenatured whey protein.

3. Denatured whey protein.
casein and increased meltability of acid casein cheese. However, no NaOH treatment made the acid casein cheese melt as much as rennet casein cheese. There was no further increase in cheese flow when more than 27.5 ml 5 N NaOH/kg was used to condition the acid casein.

Acid casein cheese conditioned with 17.5 ml 5 N NaOH/kg had less flow than when conditioned with 12.5 ml 5 N NaOH/kg. This meltability phenomenon was repeatedly observed and measured but remains unexplained. Meltability of acid casein cheese with 12.5, 17.5, or 22.5 ml 5 N NaOH/kg and rennet casein cheese were all statistically different at $P<.05$. Meltability of acid casein cheese with 27.5, 32.5, or 37.5 ml 5 N NaOH/kg was not statistically different at the same probability.

**Effect of Emulsifying Salts.** There were dramatic differences in the meltability of rennet and acid casein process cheese with different emulsifying salts (Figure 2). DSP and TSPP resulted in the greatest difference between the two kinds of cheese. Rennet casein models did not melt when these salts were used whereas acid casein models (NaOH conditioned) melted 80 and 70 mm with DSP and TSPP.

Rennet casein process cheese melted best with CIT as the emulsifying salt. The effectiveness of CIT in producing process cheese with good melting quality was shown by Templeton and Sommer (18), Rayan et al. (15), and Thomas et al. (19); CIT is very effective in complexing micellar calcium and causing disaggregation of casein micelles (9, 12).

Rennet casein process cheese prepared with SALP had slightly poorer melting properties than when prepared with CIT. The actual process by which SALP enhances meltability is not indicated in the literature, but it can be theorized that SALP chelates the casein-bound calcium in a manner similar to CIT. Rayan et al. (15) showed that emulsification by SALP was slower than with CIT; the former salt required more time in the cooker to effect emulsification.

Acid casein process cheese responded quite differently to the salts and requires a different explanation than for rennet casein process cheese. No calcium is bound to casein at the isoelectric point (pH 4.6) of this protein (23). Because there was no measurable calcium in the acid casein, calcium complexing or chelating by CIT or SALP did not occur.

Acid casein cheese made with CIT or SALP did not melt as well as rennet casein cheese made with these emulsifying salts. Figure 3 shows that there was no substantial difference in the degree of emulsification between acid and rennet casein cheeses prepared with these two salts. However, the fractures of the cheeses made with CIT are smoother than those made with SALP (Figure 3).

Use of DSP or TSPP produced acid casein process cheese with excellent melting proper-

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**Figure 1.** Meltability of rennet and acid casein (C.) process cheese using trisodium citrate as emulsifying salt. Volumetric values for acid casein cheese represent added 5 N NaOH/kg cheese.

**Figure 2.** Meltability of model process cheese with different emulsifying salts. SALP = Sodium-aluminum phosphate, DSP = disodium phosphate, TSPP = tetrasodium phosphate, and CIT = trisodium citrate.
ties. This is in sharp contrast to the rennet casein cheese prepared with these salts. TSPP and DSP may not have bound sufficient calcium in the rennet casein to allow the cheese to melt properly.

Acid and rennet casein cheeses prepared with DSP had a high degree of emulsification as evidenced by very small fat globule vacuoles, whereas TSPP produced the same degree of emulsification in rennet casein cheese, but did not overemulsify the acid casein cheese (Figure 4).

Rennet casein cheese made with TSPP, DSP, and disodium oxalate (18.46 g/kg) melted well (Table 4). These results support the theory that orthophosphates and pyrophosphates may lack

Figure 3. Process cheese prepared with: A. acid casein + trisodium citrate (CIT); B. rennet casein + CIT; C. acid casein + sodium-aluminum phosphate (SALP); D. rennet casein + SALP. The presence of fat in original cheese is indicated by void spaces (e, f), resulting from the extraction of the fat during preparation steps for SEM.
Figure 4. Process cheese prepared with: A. acid casein + disodium phosphate (DSP); B. rennet casein + DSP; C. acid casein + tetrasodium phosphate (TSPP); D. rennet casein + TSPP; E. rennet casein + TSPP + oxalate; F. rennet casein + DSP + oxalate. Void spaces (small arrows) indicate presence of fat particles in original cheese. Large arrows point at structures which are most probably calcium oxalate crystals. Emulsifying salt crystals (s) are seen in frame C.
adequate capacity to chelate calcium bound to rennet casein (6, 10, 15). Oxalate is a strong calcium-binding agent and in sufficient concentration can chelate all the calcium in milk (12). Oxalate binds calcium that is not bound by DSP and TSPP, producing rennet casein process cheese with superior meltability. Addition of disodium oxalate to these preparations reduced emulsification (indicated by larger fat particles) compared with rennet casein prepared with DSP or TSPP in the absence of oxalate (Figure 4).

Conditioning of acid casein with NaOH and an emulsifying salt may explain the improved meltability of acid casein cheese. Each salt affected the conditioning pH of the blend in the cooker differently and, thereby, the extent of solubilization of the casein. Solubilization of acid casein in this manner may be similar to the disaggregation of rennet casein due to calcium removal.

Acid casein cheese emulsified with DSP or TSPP was conditioned at high pH levels (7.55 and 7.75). This may have solubilized a sufficient amount of acid casein to produce a protein matrix around the fat globules and provide good meltability.

This reasoning, however, fails to explain the poorer meltability of acid casein cheese made with SALP. This emulsifying salt resulted in a conditioning pH of 7.65, comparable to cheese prepared with DSP or TSPP. Conditioning pH and its effective solubilization of acid casein may only partly explain the action of emulsifying salt on acid casein.

Effect of Whey Protein Addition

Meltability of process cheese decreased as the concentration of whey protein increased (Figures 5 and 6). This confirms the patent by Schulz (16) concerning a method for producing a melt-resistant process cheese. The process involves the incorporation of 3 to 7% (wt/wt) of a coagulable protein, such as "milk albumin" or "lactalbumin." Heat-induced gelation of the protein when process cheese was tested for meltability was implied in the patent.

There were no body defects or loss of emulsification in acid casein cheeses. The UWP

Figure 5. Meltability of acid and rennet casein process cheese with added undenatured whey protein.

Figure 6. Meltability of acid and rennet casein process cheese with added denatured whey protein.

### Table 4. Meltability of TSPP and DSP rennet casein process cheese with disodium oxalate as a calcium-binding agent.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Oxalate added</th>
<th>Melt distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSPP</td>
<td>No</td>
<td>13.7 ± 1.15a</td>
</tr>
<tr>
<td>TSPP</td>
<td>Yes</td>
<td>94.0 ± 5.29b</td>
</tr>
<tr>
<td>DSP</td>
<td>No</td>
<td>0.0 ± 0.0c</td>
</tr>
<tr>
<td>DSP</td>
<td>Yes</td>
<td>61.0 ± 1.73d</td>
</tr>
</tbody>
</table>

a,b,c,d Means with different letters are significantly different from each other (P<.05).

1 Statistical analysis of triplicate determinations of duplicate samples.
added to rennet casein models decreased cheese meltability and severely affected the body of the cheese. Moderate oiling-off was noted in the sample with 1.5% UWP. Severe oiling-off and a very porous surface were defects observed in samples containing 3.0 and 4.5% UWP; the latter sample collapsed and slid in the melting tube and did not exhibit a true melting property. This defect may account for the apparent increase in meltability when UWP concentration was increased from 3.0 to 4.5% (Figure 3).

The DWP added to acid casein cheese at 1.5 and 3.0% did not decrease meltability as much as when added to rennet casein cheese (Figure 4). Addition of 4.5% DWP to the acid casein cheese inhibited melting whereas in the corresponding rennet casein model, it slightly increased meltability. The increase in cheese flow with 4.5% DWP was a result of the change in cheese body previously mentioned. High levels of DWP and UWP each caused an oiling-off defect and porous structure in melted cheese made from rennet casein.

Microstructure of Model Process Cheese

The microstructure of acid or rennet casein process cheese as viewed by scanning electron micrographs aided in analysis of differences in cheese meltability. Acid casein cheese conditioned with different levels of 5 N NaOH showed marked differences in degree of emulsification. Acid casein cheese conditioned with 17.5 ml of 5 N NaOH/kg had a fine emulsion, which may be responsible for its low meltability (25 mm). Acid casein cheese conditioned with 32.5 ml of 5 N NaOH/kg had a more open structure (i.e., less complete emulsification), which may have allowed for greater meltability (58 mm). This correlation between emulsification and meltability closely agrees with the results of Rayan et al. (15).

Adding increasing amounts of whey protein to rennet casein cheese did not influence the degree of emulsification during processing. All rennet casein cheese contained various-sized fat globule spaces. As whey protein concentration increased, however, fibrous structures became apparent (Figure 7). The fibrous structures were not seen when 1.5% whey protein was added but were viable when 3.0% whey protein was added. These structures may have been responsible for the loss of cheese meltability and the oiling-off defect.

Acid casein process cheese with added whey protein did not exhibit any abnormal physical structure. All acid casein cheese was well-emulsified with uniform, small-size fat globule spaces.

CONCLUSIONS

Meltability defects in model process cheese systems cannot be attributed solely to a single constituent or process condition. Casein type, calcium concentration, whey protein concentration, type of emulsifying salt, and extent of pH conditioning of acid casein can all affect cheese meltability. These ingredients and processes affect the meltability of rennet casein and acid casein process cheese in different ways.

A relationship between microstructure and meltability of process cheese made with rennet casein agrees with the results reported by other researchers; more complete emulsification resulted in poorer meltability in both process natural and rennet casein cheese (15). The distribution of fat globule particles (by SEM analysis) of acid casein process cheese was not related to cheese meltability. The interactive
effects of casein type, calcium concentration, emulsifying salt, and pH conditioning of acid casein did not make it possible to predict meltability based on microstructure. The meltability defect noted when CCP is used in process cheese should not be attributed to any single causative agent or process.

Recovery of whey protein in CCP makes the use of UF technology attractive as far as yield and nutritional enhancement. The whey proteins certainly inhibit meltability but are not the only cause of the cheese melt defect. The CCP at 37% moisture prepared from UF whole milk retentate has approximately 4.0% (wt/wt) whey protein. There was some melting in model systems containing this level of whey protein.

Higher calcium levels than in natural cheese used for processing may be another cause of the melt defect in CCP. Effective calcium sequestering with oxalate made the rennet casein process cheese very meltable. Emulsifying salts varied in their ability to sequester casein-bound calcium. Calcium levels exceeding that found in natural cheese may present more difficult and different emulsification problems in processing CCP.

Acidification of milk prior to ultrafiltration can reduce retained calcium in UF whole milk retentate and subsequently in CCP. The pH adjustment-calcium level interactions must be correlated with the type of emulsifying salt to emulsify the cheese system correctly for adequate meltability.

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