Reduced Fat Cheddar Cheese from Condensed Milk.
2. Microstructure

D. L. ANDERSON and V. V. MISTRY

Minnesota-South Dakota Dairy Foods Research Center
Dairy Science Department
South Dakota State University
Brookings 57007-0647

ABSTRACT

The microstructure of reduced fat Cheddar cheese manufactured from condensed milk was evaluated. Four cheese milk treatments were applied: control (uncondensed, 10.3% total solids) and condensed, 15.4, 18.3, and 22.2% total solids. Fat and moisture contents of the cheeses were 18.5 and 46.0; 18.2 and 45.1; 18.8 and 43.3; and 17.6 and 43.0%, respectively. An interrelationship was observed among cheese milk treatments, cheese body and texture scores, and microstructure from the cheeses. Body and texture scores decreased as concentration increased, and microstructure became increasingly rough and dense, with an uneven protein matrix. Control cheese body was rubbery, and the microstructure as observed by scanning electron microscopy was smooth. Body and texture of cheese from condensed milk with 22.2% solids was extremely firm and crumbly, and the microstructure reflected the firm and crumbly texture, with an uneven, layered protein matrix with poor curd particle fusion. Manufacturing processes (condensing) applied to cheese milk and cheese composition had an effect on microstructure and therefore affected the body and texture of reduced fat Cheddar cheese.

(Key words: microstructure, reduced fat Cheddar cheese, scanning electron microscopy)

INTRODUCTION

Results of a previous study (1) on the manufacture, composition, and ripening of one-third reduced fat Cheddar cheese (RFCC) from condensed milk indicated that condensing of cheese milk had an impact on cheese body and texture. Milk condensed to high total solids (TS) (18.3 and 22.2%) produced firm and crumbly cheeses that improved only slightly with age. The firm and crumbly body and texture in condensed milk cheeses may be due to their high ash content (≤4.7%) compared with that of control cheeses (4%). A high mineral content, especially that of calcium, may adversely affect cheese body and texture (10).

Cheddar cheese consists primarily of a mixture of milk protein, fat, minerals, and lactose in which milk proteins form the major structural network (9, 10). Modifications in cheese composition caused by changes in milk composition alter the body and texture. In addition to the change in mineral content in cheese, such as that obtained through condensing of cheese milk, fat also affects body and texture (5). The protein matrix, mainly casein, that is interlaced with fat gives cheese its smooth, firm, pliable body and texture (9). In RFCC, the body and texture tend to be firm and rubbery because fewer fat globules are dispersed in the protein matrix (5).

Results of a recent study (12) indicated that fat plays a significant role in the microstructure of many full fat and reduced fat hard and semi-hard cheeses. In reduced fat cheeses, fewer fat globules were interspersed throughout the protein matrix although the protein...
matrix remained relatively smooth. In reduced fat cheeses, the protein matrix dominated the structural network of cheese. These changes in the protein matrix confirm that cheese composition affects microstructure. A study of the microstructure of cheese would be valuable for a better understanding and development of methods to improve the body and texture of reduced fat cheeses, especially those made from condensed milk. The objectives of this study were to evaluate the microstructure of RFCC made from condensed milk and to relate structural attributes to body, texture, and cheese manufacturing procedures.

Although new FDA labeling regulations have specific definitions for fat descriptors, such as reduced fat, low fat, fat-free, and others (11), the term “reduced fat” is used in this paper to refer to all levels of fat reduction.

### MATERIALS AND METHODS

#### Cheese Milk and Cheese Manufacture

Preparation of cheese milk and cheese manufacturing procedures were described earlier (1): five replicates of raw whole milk were skimmed (<5% fat) in a DeLaval triprocessor (Alfa Laval, Fort Lee, NJ); the skim milk was pasteurized at 63°C for 30 min in a vat, plate-cooled (2 to 3°C), and stored until needed at 3 to 4°C. The pasteurized skim milk was split into four treatments (TRT): A, control, uncondensed; B, C, and D, condensed to approximately 1.5, 1.8, and 2.0 times the original TS, respectively. Skim milk, preheated to 38°C, was condensed in a pilot plant single-stage rising film Blaw-Knox® evaporator (C. E. Rogers, Mora, MN), rapidly cooled in an ice bath, and stored at 3 to 4°C until needed. Cream (40.6%) separated from whole milk was pasteurized at 74°C for 30 min and added to the condensed skim milk to obtain the desired composition and weight in TRT A to D: A, control, uncondensed (10.3% TS, 1.7% fat,

### TABLE 1. Composition\(^1\) of reduced fat Cheddar cheese from condensed milk.

<table>
<thead>
<tr>
<th>Component</th>
<th>Treatment(^2)</th>
<th>A (%)</th>
<th>B (%)</th>
<th>C (%)</th>
<th>D (%)</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td></td>
<td>18.5(^a)</td>
<td>18.2(^ab)</td>
<td>18.8(^b)</td>
<td>17.6(^b)</td>
<td>.19</td>
</tr>
<tr>
<td>Moisture</td>
<td></td>
<td>46.0(^b)</td>
<td>45.1(^b)</td>
<td>43.3(^c)</td>
<td>43.0(^b)</td>
<td>.35</td>
</tr>
<tr>
<td>Total protein</td>
<td></td>
<td>30.6(^c)</td>
<td>31.2(^b)</td>
<td>31.3(^b)</td>
<td>32.5(^a)</td>
<td>.21</td>
</tr>
<tr>
<td>NaCl</td>
<td></td>
<td>1.3(^b)</td>
<td>1.3(^b)</td>
<td>1.5(^b)</td>
<td>1.6(^a)</td>
<td>.04</td>
</tr>
<tr>
<td>FDC(^3)</td>
<td></td>
<td>34.2(^a)</td>
<td>33.1(^b)</td>
<td>33.1(^b)</td>
<td>30.9(^c)</td>
<td>.36</td>
</tr>
<tr>
<td>MFFC(^4)</td>
<td></td>
<td>56.4(^a)</td>
<td>55.1(^b)</td>
<td>53.3(^c)</td>
<td>52.3(^a)</td>
<td>.42</td>
</tr>
</tbody>
</table>

\(^a,b,c,d\)Means in rows with like superscripts do not differ \((P > .05)\).
\(^1\)Mean of five replicates.
\(^2\)Treatments: A = control, uncondensed milk [10.3% total solids (TS)]; B = condensed milk (15.4% TS); C = condensed milk (18.3% TS); D = condensed milk (22.2% TS).
\(^3\)Fat in dry cheese.
\(^4\)Moisture in fat-free cheese.

### TABLE 2. Body and texture scores\(^1\) of reduced fat Cheddar cheese from condensed milk.

<table>
<thead>
<tr>
<th>Treatment(^2)</th>
<th>1 mo</th>
<th>6 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6.42(^a)</td>
<td>8.22(^A)</td>
</tr>
<tr>
<td>B</td>
<td>5.82(^a)</td>
<td>6.16(^A)</td>
</tr>
<tr>
<td>C</td>
<td>4.88(^a)</td>
<td>5.22(^A)</td>
</tr>
<tr>
<td>D</td>
<td>4.76(^a)</td>
<td>5.16(^A)</td>
</tr>
<tr>
<td>SE</td>
<td>.06</td>
<td>.10</td>
</tr>
</tbody>
</table>

\(^a,b,c,d\)Means in columns with like superscripts do not differ \((P > .05)\).
\(^A,B,C\)Means in rows with like superscripts do not differ \((P > .05)\).
\(^1\)Mean of five replicates; score scale: 1 = poor to 10 = excellent.
\(^2\)Treatments: A = control, uncondensed milk [10.3% total solids (TS)]; B = condensed milk (15.4% TS); C = condensed milk (18.3% TS); D = condensed milk (22.2% TS).
Figure 1. Scanning electron micrograph of a full fat Cheddar cheese. Black arrow points at void representing fat globule.

3.2% total protein, and 149 kg); B, condensed, (15.4% TS, 2.4% fat, 4.8% total protein, and 99 kg); C, condensed (18.3% TS, 2.9% fat, 5.7% total protein, and 99 kg); and D, condensed (22.2% TS, 3.3% fat, 7.0% total protein, and 99 kg). The RFCC manufacturing characteristics, composition, yield, ripening, and sensory evaluation were described in detail earlier (1). In the present study, the microstructure of these cheeses was evaluated.

Microstructure

Modifications of published methods (6, 15) were used for preparing cheese samples at 20 to 22°C for scanning electron microscopy. Samples were cut with a razor blade into approximately 4-mm cubes and immersed in a 1.4% glutaraldehyde fixative (E. Merck Science, Ft. Washington, PA) for 30 min. Samples were washed in six changes of distilled water, 30 s per change, freeze fractured in liquid nitrogen to approximately 1-mm pieces, and defatted with chloroform for 60 min; six changes lasted 10 min each. Samples were dehydrated over 90 min in a graded series of ethanol (30, 50, 70, 80, 90, and 100%) and critical point dried (Poloran critical point dryer®; Ted Pella, Inc., Redding, CA). The dried samples were mounted on painted aluminum stubs with silver paint (E. Merck Science), allowed to dry, and coated with 20-nm gold and palladium for 6 min in a Technics Hummer VI sputter coater (Anatech, Ltd., Alexandria, VA). All prepared, fixed samples were stored in a desiccator at 20°C. Samples were viewed in an ISI Super IIIA scanning electron microscope (International Scientific Instruments, Glen Ellyn, IL; now TopCon Technologies Inc., Pleasanton, CA) operated at 15 kV. Photomicrographs were taken on a Type 55 Polaroid® 50 ASA film (Polaroid Corp., Cambridge, MA). Microstructure of cheeses was evaluated after 1 wk and 3 and 6 mo of ripening.

Statistical Analysis

Data were analyzed by analysis of variance using the general linear models procedure of SAS (13). Means were separated by Fisher's
Figure 2. A) Cheese from treatment (TRT) A [uncondensed, 10.3% total solids (TS)] at 1 wk of age. The protein matrix is smooth. B) Cheese from TRT B (condensed, 15.4% TS) at 1 wk of age. Protein matrix is slightly layered.
C) Cheese from TRT C (condensed, 18.33% TS) at 1 wk of age. The protein matrix is layered. D) Cheese from TRT D (condensed, 22.2% TS) at 1 wk of age. The protein matrix layered and rippled. White arrows point at void representing fat globules.
Figure 3. A) Cheese from treatment (TRT) A (condensed, 10.3% total solids (TS)) at 6 mo of age. The protein matrix is smooth. B) Cheese from TRT B (condensed, 15.4% TS) at 6 mo of age. Protein matrix is slightly layered with elongated void spaces, an effect that is due to aging.
C) Cheese from TRT C (condensed, 18.3% TS) at 6 mo of age. The protein matrix has elongated void spaces, an effect that is due to aging. Incomplete curd fusion is indicated by open black arrow. D) Cheese from TRT D (condensed, 22.2% TS) at 6 mo of age. The protein matrix is layered. White arrows point at void representing fat globules.
protected least significant difference at the \( P < .05 \) for all data (14).

**RESULTS AND DISCUSSION**

Composition, yield, and sensory data of RFCC were reported earlier (1). Fat content and fat in dry cheese were 18.5, 18.2, 18.8, 17.6, and 34.2, 33.1, 33.1, and 30.9\% in cheeses from TRT A, B, C, and D, respectively (Table 1). Moistures in fat-free cheese (MFFC) were 56.4, 55.1, 53.3, and 52.2\% in cheese from TRT A, B, C, and D, respectively. The MFFC is important for determination of body of hard cheeses, and the recommended range is 52 and 56\% (10). The MFFC was lower in cheeses from condensed milk (TRT B, C, and D). The decrease in MFFC as concentration increased may be a factor causing the firm, crumbly body in cheeses from these TRT (Table 2).

All cheeses in this study exhibited a microstructure typical of reduced fat cheese (12); i.e., the structure consisted mainly of a protein matrix with a small number of fat globules dispersed in the matrix. In full fat Cheddar cheese, a large number of fat globules are present, which appear to be larger and interconnected. The protein matrix in full fat cheese is not as dominating as in RFCC (Figure 1). In a recent study (12), a distinct relationship was observed between fat content and cheese microstructure in several types of full fat and reduced fat cheeses. Fat globule distribution and area decreased as the cheese fat content decreased, suggesting that microstructure is also affected by composition, particularly by fat. The protein matrix of the RFCC (one-third to no fat) remained relatively smooth.

Figure 2 illustrates the microstructure of all cheese TRT at the beginning of the ripening period. All TRT were subjected to the same cheese manufacturing procedure. Differences in cheese milk composition and resulting differences in cheese composition may have altered the cheese microstructure (7).

Cheese from TRT A exhibited a relatively smooth and flat protein matrix (Figure 2A) that is similar to that found in previous research with conventional full fat and reduced fat cheeses (6, 12, 15). The individual identity of curd particles in TRT A cheeses was not visible, perhaps because curd fusion was complete. The protein matrix in the condensed milk cheeses had a rippled effect and appeared to be layered as concentration increased (Figure 2, B to D), which was especially noticeable in cheese from TRT D (Figure 2D). The protein matrix in these cheeses was not continuous but had tiny holes that may be left by incomplete curd fusion of curd particles (Figure 3C). These cheeses had lower \( P < .05 \) body and texture scores (Table 2) than the TRT A cheese, which had a smooth protein matrix. Results were similar in a study by Green et al. (4) with full fat Cheddar cheese made from milk concentrated by UF one-, two-, and fourfold. The protein matrix of these cheeses was coarse, and the body was firm and crumbly at 5 and 28 wk. These body characteristics were attributed to cheese milk TRT (UF) rather than to cheese-making parameters (4).

The microstructure of cheese from all TRT from 1 wk to 6 mo changed considerably, although the microstructure at 3 mo was similar to that at 1 wk (micrographs not shown). After the cheeses had aged for 6 mo, some of the void spaces in all cheeses appeared elongated (Figure 3, A to D). This elongation is a typical indication of body development in a ripening hard cheese (8). At 1 wk, distinct differences existed among TRT, which were still apparent at 6 mo. The protein matrix of TRT A cheese remained smooth (Figure 3A), which may be related to the increased rate of proteolysis (1), leading to an improved body and texture in the cheese (Table 2). Earlier data (1) indicated that proteolysis and bacterial numbers decreased as milk concentration increased. Total anaerobic bacterial counts in cheeses at 6 mo for TRT A, B, C, and D were \( 2.0 \times 10^8, 2.5 \times 10^7, 1.9 \times 10^7, \) and \( 1.1 \times 10^7 \) cfu/ml, respectively (1). The lack of proper curd fusion in the protein matrix of cheeses made from condensed milk appeared at all ages (Figure 2, B to D, and Figure 3, B to D). This characteristic did not disappear with age (Figure 3, B to D) and may be associated with the low body and texture scores, even after 6 mo of maturation (Table 2). Body and texture of cheeses from TRT C and, to a greater extent, from TRT D were extremely firm and crumbly.

The decreased rate of proteolysis and bacterial numbers as milk concentration increased were attributed to increased salt to moisture
ratio and lower MFFC in the condensed milk cheeses (1). In the condensed milk cheeses, the protein matrix did not break down to the extent that it did in cheese from TRT A. The microstructure, rate of proteolysis, and bacterial numbers support a decrease in bacterial activity as concentration increased. Proteolysis and microstructural characteristics were similar in full fat Cheddar cheeses made from UF milk (3, 4).

Body and texture scores decreased \( (P < .05) \) as concentrations increased, but scores improved over time (Table 2). Body and texture of RFCC tended to be firm and less elastic than that of full fat Cheddar cheese (2, 5). This defect was more pronounced in cheeses made from condensed milk (1).

CONCLUSIONS

Body and texture reflect the microstructure of cheese. Observations from this study and previous work (1, 12) indicate that cheese microstructure is affected by composition and manufacturing practices. The TRT A cheese was firm and rubbery, and the microstructure was smooth. This effect was due to proteolysis and subsequent body breakdown. The protein matrix of cheese from condensed milk, especially TRT D cheese, appeared to be rippled and layered at 1 wk. Because of partial proteolysis, the rippled effect decreased after 6 mo, although the cheese matrix was still layered, and curd fusion was poor. This effect was probably due to condensing of cheese milk prior to cheese making. Microstructure and body and texture scores for cheeses from TRT B and C ranged between those for cheeses from TRT A and D. These structural characteristics of condensed milk cheeses may explain the firm, crumbly, and mealy body and texture of these cheeses.

ACKNOWLEDGMENTS

The authors are grateful to the Minnesota-South Dakota Dairy Foods Research Center for funding this project and to W. Lee Tucker, South Dakota State University, for his valuable help with statistical analysis.

REFERENCES