Influence of Microfluidization of Milk on Cheddar Cheese Composition, Color, Texture, and Yield

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ABSTRACT

The microfluidization of milk used to manufacture Cheddar cheese was investigated with the ultimate objective of whitening the cheese. Four vats of cheese were prepared simultaneously from 2 kg of the following milks: untreated milk (control), milk microfluidized at 7 MPa, and milk reconstituted to its original composition made from cream microfluidized at 14 or 69 MPa. Whey was analyzed for fat and protein losses (fines), and cheese was analyzed for composition, color, and texture. Microfluidized milk produced cheese that was significantly whiter but higher in moisture; means were 35.0% for the control and 37.6, 38.4, and 39.3% for cheeses made from milks microfluidized at 7, 14, and 69 MPa, respectively. Protein and fat in the DM, respectively, decreased and increased with microfluidization pressure. In the whey of control cheese, fat loss was higher, and fewer fines were collected, than for treated cheese. Firmness for cheese made from microfluidized milk at 7 MPa was not significantly different from the control; however, microfluidization of cream at 14 or 69 MPa significantly and progressively decreased firmness. The significant increase of yield for cheeses made from treated milk was explained by a better retention of fat into the cheeses and increased cheese moisture. Microfluidization also whitened Cheddar cheese, but its effects on texture and composition were less important for milk microfluidized at 7 MPa than for cream separately microfluidized at 14 or 69 MPa.

(Key words: microfluidization, Cheddar, cheese yield, color)

Abbreviation key: FDC = fat fraction in dry cheese, MF = milk fat, P:F = protein to fat ratio.

INTRODUCTION

In the province of Québec, a large proportion of Cheddar cheese is a mild uncolored cheese that has a light yellow color that consumers dislike. Moreover, important seasonal variation of cheese color occurs because of differences in the cow diet and the carotenoid content in the milk fat (MF) fraction. Formerly, this undesirable color was masked by use of titanium dioxide as a whitening agent, but this additive was prohibited from the milk industry in 1989 (15).

Other coloring agents, such as chlorophyll, can be applied to whiten Feta (14) and Blue cheese (22), but almost all of the latter is currently made from homogenized milk to produce lighter color cheese (22). Recently, Jana and Upadhyay (18) reviewed studies on cheese making from homogenized milk. Homogenization of milk produces Cheddar cheese with a less intense yellow color (26), similar to the color of goat cheese (21). At an equivalent fat content, goat milk has three times more MF globules of 1.5 μm in diameter than does cow milk (19). This finding supports the hypothesis that cheese color is partly related to the number and size of MF globules.

Homogenization whitens milk and cream (5, 17). Milk color results from two opposite phenomena: 1) the reflection of yellow light by the carotenoids, liposoluble pigments that give milk its characteristic creamy color, and 2) the scattering of light by the fat globules, which results in a clear white appearance (6). When milk is homogenized, the larger MF globules are dissociated into numerous small ones. Con-
sequentially, light scattering is increased, and milk appears whiter. The use of homogenization in Cheddar manufacturing has been studied primarily with the aims of increasing cheese yield (25, 28) and improving the texture of Cheddar cheese made from lowfat milk (13) and concentrated milk (16). Homogenization increased fat and moisture retention and affected cheese body and texture by a reduction of curd firming and syneresis. These modifications are caused by the decrease in curd tension from homogenization as a result of the dispersion of MF globules. Formation of complexes between caseins and MF globules to form new membranes (17) decreases the amount of casein available to form the coagulum. Therefore, separate homogenization of cream could partially compensate for the decrease of curd tension brought about by milk homogenization. Microfluidization, the homogenization technique used in this study, is based on the following principle: the milk is pumped at high pressure into a chamber and split into two streams, which are projected against one another at an angle of 180° (10). Compared with standard homogenization processes, microfluidization of milk at equivalent pressure produces a narrower distribution of MF globules (27).

Only a few studies have investigated the homogenization of milk and separate homogenization of cream as processes for whitening Cheddar cheese. The objectives of this work were to measure the effects of microfluidization, a relatively new homogenization technique, on the composition, color, texture, and yield of Cheddar cheese.

MATERIALS AND METHODS

Milk Processing

Bulk raw milk (Natrel, Québec, PQ, Canada) was heated to 40°C and separated into cream and skim milk using a Wesfalia Separator (type LWA 205, Centrico Inc., Englewood, NJ). The fat and protein contents of each fraction were immediately determined with a Milko-Scan 133B (N. Foss Electric, Hillerød, Denmark). Separated cream and skim milk were blended to form 15% MF cream and 5 L of whole milk with a total protein to fat (P:F) ratio of .88. One-half of the whole milk was not microfluidized and was used as the control. The remaining milk and the two portions of 15% MF fat cream were then microfluidized (Microfluid M-110™ apparatus; Microfluidic Corporation, Newton, MA) at 7, 14, and 69 MPa, respectively, at 50°C to minimize protein denaturation (17). Lots of 2 L of P:F standardized whole milk were reconstituted by blending the corresponding portion of microfluidized cream with the separated skim milk. All milks were immediately heated at 63°C for 30 min prior to cheese making.

Cheese Making

Four vats of cheese were simultaneously made in a temperature-controlled water bath using the four cheese milk treatments. Pasteurized milk (2 kg) was cooled to 32°C and weighed in 2.7-L plastic containers. Each vat was inoculated (.016%, vol/wt) with the same direct vat starter culture (number 911). After 50 min, .025% of CaCl₂ and then .025% of commercial rennet were added to each vat. Starter, rennet, and CaCl₂ were from Chr. Hansen's Laboratory (Milwaukee, WI). Coagulated milk was cut into 7-mm cubes 30 min later. Curd was allowed to heal for 10 min and then was heated to 38°C over 40 min. Fifty percent of the whey was drained, and the curds were then isothermally stirred for an additional 30 min prior to final removal of whey. Whey was filtered over a 1.5-mm mesh screen, and the recovered curd particles were reincorporated to the cheese curd. Curd was cheddared until the pH reached 5.3 when it was cut into pieces of 30×15×20 mm and dry salted (.25% of the milk). The cheese was pressed for 16 h at room temperature (22°C) in a round mold at 6.15 kPa. Cheese was vacuum packed and stored at 13°C for 21 d. Whey was collected up to pressing and immediately stored at 4°C until analysis.

Cheese Sampling and Analysis

Chemical Analysis. Sampling and chemical analysis were carried out immediately after removal of cheese from the press. A sample (.25 of a round) from the center to the ring was taken from each cheese, coarsely grated, and mixed. Moisture was assessed by drying of 2 g of cheese at 100°C in a vacuum oven for 4 h.
(2) in five replicates. Fat was determined by a modified Babcock test (12); the first centrifugation time was increased to 7.5 min (1.5-fold) to separate the homogenized MF globules. Total nitrogen was measured by the Kjeldahl method (2) and converted into protein using a 6.38 conversion factor. Salt was determined by an atomic absorption spectrophotometer (model 603; Perkin-Elmer, Palo Alto, CA) (7).

Analyses for fat, protein, and salt contents were in duplicate. The pH was measured using a cheese electrode (Radiometer America Inc., Westlake, OH).

**Texture Analysis.** Cheeses were assessed at 3 wk of age for texture by the Instron Universal Testing Machine (model 1101; Instron Corp., Canton, MA) using texture profile analysis. Sampling was at 4°C according to Casiraghi et al. (8). Cylinders (1.0 cm high and 1.1 cm in diameter) were bored (24), wrapped in plastic film, placed in an airtight container at 22°C for 3 h, and then compressed to a deformation of 80% by a cylinder of 5.6 cm attached to the 500-kg cell. The deformation speed of the sample was 50 mm/min. Firmness was the force involved in the first bite to compress a sample (32). Firmness for each cheese represented the mean of 12 assessments.

**Color Analysis.** Color data were reported using the Hunter Lab system in which L values represent the lightness, a values indicate the red-green component, and b values indicate the yellow-blue component. Color analysis was carried out with the Colorgard System 1000/05 colorimeter (Pacific Scientific Gardner/Neotec, Silver Spring, MD). A 3-mm thick slice from the bottom of each cheese was placed in a Petri dish, and four measurements were made on each sample. The color data were then expressed as lightness, hue, and saturation. The lightness relates to the intensity of light reaching the eyes (33). The hue angle, expressed as tan⁻¹ a/b, relates to the type of color perceived, and saturation, (a² + b²)½, relates to purity representing the degree of dilution with white light (9).

**Yield Determination**

Actual yield \( (Y_{\text{act}}) \), expressed as kilograms of cheese per 100 kg of cheese milk, was obtained by accurate weighing of the amount of milk (to the nearest 5 g) and of the cheese (to the nearest .01 g) immediately after pressing. Theoretical cheese yield \( (Y_{\text{th}}) \) was calculated by the van Slyke and Price cheese formula (34):

\[
Y_{\text{th}} = \frac{(.93 \times F + C - .1) \times 1.09}{1 - M}
\]

where F and C are the fat and casein contents of the cheese milk (kilograms per 100 kg), respectively, and M is the cheese moisture fraction.

Yield \( (Y_{\text{adj}}) \) was adjusted to that of cheese containing 37% moisture and 1.7% salt, including a term for the adjustment of fat-free whey solids (12).

\[
Y_{\text{adj}} = Y_{\text{act}} \times \left( \frac{1 - WSC_{\text{adj}}}{1 - WSC_{\text{std}}} \right)
\]

where WSC_{sef} is the fraction of fat-free whey solids in cheese, accounting for solute exclusion of cheese protein, M is the fraction of moisture in cheese, SC is the fraction of salt in cheese, std and act refer to the cheese adjusted to standard composition and to the actual cheese, respectively; WSC_{sef} was calculated for each vat of cheese (12) using a solute exclusion factor (sef) of .5 and the actual (WSC_{sefact}) and standard (WSC_{sefstd}) moisture fraction in cheese.

Fat (K_F) and protein (K_P) recovery coefficients have also been calculated as follows:

\[ K_F = (F_C \times Y_{act})_F \]  \[ K_P = (P_C \times Y_{act})_P \]  

where F_C is the fat fraction in cheese, and P_C is the protein fraction in cheese.

Casein recovery (K_C) was indirectly calculated using a transformed van Slyke formula because casein content in cheese was undetermined:

\[ K_C = [(Y_{act} / 1.09) (1 - M) - (K_F \times F)] / C. \]

**Statistical Analysis**

A randomized block design with four treatments was used for statistical analysis. The experiment was replicated six times. Analysis of variance was used to evaluate the effects of microfluidization on cheese composition, color, texture, and yield. Differences between means were tested according to Scheffe test using a general linear procedure (PROC GLM) of the SAS statistical package (30). Significant differences were tested at \( P = .05 \) using the \( F \) test. The standard errors were used to calculate the Fisher least significant difference between means for the different treatments. The Scheffe test allows all possible contrasts to be tested with an error rate no larger than planned. Consequently, it is conservative, and the power may be low compared with that of the Fisher protected least significant difference.

**RESULTS**

**Physical and Chemical Characteristics of Milk**

**MF Globule Size.** The MF globules of whole milk microfluidized at 7 MPa showed a distribution profile similar to that of cream microfluidized at 69 MPa, with two distinct populations of globules (Figure 1). Approximately 18% of the MF volume consisted of globules with a mean diameter of 190 nm, and the remaining volume consisted of globules of approximately 1000 nm. A smaller mean diameter and a narrower distribution of MF globules were obtained for the milk microfluidized at 7 MPa than for the cream microfluidized at 69 MPa, with 710 ± 290 and 1020 ± 450 nm, respectively. Globules of 15% MF cream microfluidized at 14 MPa showed only a single population; the distribution was large, with an average diameter of 1090 ± 730 nm (Figure 1), clearly indicating that, at equivalent MF contents, higher microfluidization pressures produced better process efficiency in size reduction.

**Milk Composition.** The compositions of the milks used in cheese-making trials are reported in Table 1. From the ANOVA, no significant difference was observed for the fat, protein, and DM contents of the experimental milks. A P:F in the cheese milk of .88 was used for the cheese milk standardization. Casein content of milk usually shows seasonal variations (4); our productions were carried out within the same season to minimize this effect. The mean casein to fat ratio was .68, which is slightly lower than the optimal ratio of .70 for Cheddar cheese (4). A previous study (1) showed that...
homogenization of whole milk at high pressures decreased casein nitrogen. Decrease in the casein percentage for milk microfluidized at 7 MPa was slight but did not occur for microfluidization of cream at 14 or 69 MPa (Table 1).

**Whey Composition**

The composition of whey provided indirect information on the cheese-making properties of the microfluidized milks. For control cheese, loss of fat and DM in the whey was significantly higher \((P < .05)\) than for the microfluidized milks, but fewer fines were collected in the whey (Table 2). This difference may indicate the production of a firmer coagulum from untreated milk, which handled more easily at cutting, as previously observed (17). Curds from microfluidized milks were brittle, and fines tended to increase with microfluidization pressures (Table 2). The significant decrease of MF in the whey for microfluidized treated cheese milks influenced cheese composition and may be related to the increased cheese yield for microfluidized treatments.

**Physical and Chemical Characteristics of Cheese**

**Composition.** As expected, microfluidized milk and cream led to higher moisture cheeses (Table 3). Moisture content increased by about 7, 10, and 12% for cheeses from milk microfluidized at 7 MPa and for cream at 14 and 69 MPa, respectively, compared with that

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**TABLE 1.** Composition of milk used in cheese-making trials.

<table>
<thead>
<tr>
<th>Microfluidization pressure</th>
<th>Milk</th>
<th>Cream</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 MPa</td>
<td>7 MPa</td>
<td>14 MPa</td>
</tr>
<tr>
<td>Fat, %</td>
<td>.365</td>
<td>.363</td>
</tr>
<tr>
<td>Total protein, %</td>
<td>.319</td>
<td>.317</td>
</tr>
<tr>
<td>Casein, %</td>
<td>.244</td>
<td>.241</td>
</tr>
<tr>
<td>True protein, %</td>
<td>.300</td>
<td>.298</td>
</tr>
<tr>
<td>Total protein:fat</td>
<td>.875</td>
<td>.873</td>
</tr>
<tr>
<td>Casein:fat</td>
<td>.668</td>
<td>.664</td>
</tr>
<tr>
<td>Casein:true protein</td>
<td>.813</td>
<td>.808</td>
</tr>
<tr>
<td>DM, %</td>
<td>12.25</td>
<td>12.26</td>
</tr>
</tbody>
</table>

1True protein = (total N - NPN) × 6.38.

2\(n = 6\) for all analyses.

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**TABLE 2.** Mean composition of whey at draining in cheese-making trials \((n = 6)\).

<table>
<thead>
<tr>
<th>Microfluidization pressure</th>
<th>Milk</th>
<th>Cream</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 MPa</td>
<td>7 MPa</td>
<td>14 MPa</td>
</tr>
<tr>
<td>Fat, %</td>
<td>.52a</td>
<td>.23b</td>
</tr>
<tr>
<td>Total protein, %</td>
<td>.69a</td>
<td>.88a</td>
</tr>
<tr>
<td>Casein, %</td>
<td>.02a</td>
<td>.04a</td>
</tr>
<tr>
<td>Fines, g/kg</td>
<td>.85a</td>
<td>.103b</td>
</tr>
<tr>
<td>True protein, %</td>
<td>.65a</td>
<td>.65a</td>
</tr>
<tr>
<td>DM including fines, %</td>
<td>7.00a</td>
<td>6.75b</td>
</tr>
</tbody>
</table>

1Means within the same row with the same superscript letter are not significantly different \((P > .05)\) based on the Scheffe test (30).

2\((Total N - NPN) \times 6.38.\)

---

TABLE 3. Mean composition at 1 d of age of Cheddar cheeses obtained from untreated and microfluidized milk (n = 6).

<table>
<thead>
<tr>
<th>Microfluidization pressure</th>
<th>Milk (n = 6)</th>
<th>Cream (n = 6)</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 MPa</td>
<td>35.00a</td>
<td>37.56b</td>
<td>1.52</td>
</tr>
<tr>
<td>7 MPa</td>
<td>34.42b</td>
<td>38.42b</td>
<td></td>
</tr>
<tr>
<td>14 MPa</td>
<td>25.47a</td>
<td>33.42b</td>
<td></td>
</tr>
<tr>
<td>69 MPa</td>
<td>1.69a</td>
<td>22.95b</td>
<td></td>
</tr>
<tr>
<td>LSD</td>
<td>53.06</td>
<td>1.43b</td>
<td></td>
</tr>
<tr>
<td>Moisture, %</td>
<td>54.36b</td>
<td>54.54b</td>
<td></td>
</tr>
<tr>
<td>Fat, %</td>
<td>53.66b</td>
<td>54.42b</td>
<td></td>
</tr>
<tr>
<td>Protein, %</td>
<td>39.28a</td>
<td>36.86b</td>
<td></td>
</tr>
<tr>
<td>Salt, %</td>
<td>5.28a</td>
<td>5.30a</td>
<td></td>
</tr>
</tbody>
</table>

*a,b,c* Means within the same row with the same superscript letter are not significantly different (P > .05) based on the Scheffe test (30).


TABLE 4. Evaluation of quality attributes of Cheddar cheese from untreated and microfluidized milks: 1) mean firmness assessed after 21 d storage at 13°C by compression tests; 2) mean color data measured after removal from the press (n = 6).

<table>
<thead>
<tr>
<th>Microfluidization pressure</th>
<th>Milk (n = 6)</th>
<th>Cream (n = 6)</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 MPa</td>
<td>49.06a</td>
<td>40.00a</td>
<td>14.35</td>
</tr>
<tr>
<td>7 MPa</td>
<td>27.89b</td>
<td>24.27b</td>
<td></td>
</tr>
<tr>
<td>14 MPa</td>
<td>82.78a</td>
<td>17.31b</td>
<td></td>
</tr>
<tr>
<td>69 MPa</td>
<td>85.41b</td>
<td>17.15b</td>
<td></td>
</tr>
</tbody>
</table>

*a,b* Means within the same row with the same superscript letter are not significantly different (P > .05) based on the Scheffe test (30).

1Scale from 0 = black to 100 = white.
2Degree of dilution with white light.
3Relates to yellowness of the cheese.
TABLE 5. Actual, theoretical, moisture-adjusted and salt-adjusted yields$^1$ of Cheddar cheese from untreated and microfluidized milks expressed in kilograms of cheese per 100 kg of milk.

<table>
<thead>
<tr>
<th>Microfluidization pressure</th>
<th>Milk (kg)</th>
<th>Cream (kg)</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 MPa</td>
<td>9.38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.89&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.28</td>
</tr>
<tr>
<td>7 MPa</td>
<td>10.20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>9.83&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.18</td>
</tr>
<tr>
<td>14 MPa</td>
<td>10.38&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.14&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.19</td>
</tr>
<tr>
<td>69 MPa</td>
<td>10.57&lt;sup&gt;b&lt;/sup&gt;</td>
<td>10.15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.19</td>
</tr>
<tr>
<td>LSD</td>
<td></td>
<td>1.033&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.033</td>
</tr>
</tbody>
</table>

$^a,b$Means within the same row with the same superscript letters are not significantly different ($P > .05$) based on the Scheffe test (30).

<sup>1</sup>Adjusted to standard cheese composition of 37% moisture, 1.7% salt, and taking into account whey solids (2).

<sup>2</sup>Calculated from van Slyke and Price formula (1).

different ($P > .05$) in firmness from the control (Table 4). Microfluidization of cream at 14 or 69 MPa prior to reincorporation in the cheese milk produced cheeses with a soft and sticky texture, and firmness decreased by 43 and 50%, respectively, compared with that of the control (Table 4).

Yield. Theoretical yields calculated from milk composition by the van Slyke formula were very similar for control and experimental cheeses (Table 5). Actual yield, expressed as kilograms of cheese per 100 kg of milk, was significantly lower for control cheese than for treated cheeses. Yield for treated cheeses increased from 8.7 to 12.7% as microfluidization pressure increased (Table 5).

Yield adjustment was used to correct for yield variation because of cheese composition and to compare yield data on the basis of a standardized cheese composition. Yield adjustment was performed to make cheese composition constant for salt and moisture, including whey solids. According to Emmons et al. (12), whey solids should be included when moisture differences are due to differences in the amount of whey expelled from the curds, particularly when these moisture differences are large. The mean for adjusted yield for control cheese was 9.72 kg/100 kg and was significantly lower than that for treated cheeses. As for actual yield, adjusted yields from various microfluidized milks were not significantly different. Fat recovery for control cheese was significantly lower than for treated cheeses. However, protein and casein recoveries were similar for all cheeses (Table 6).

**DISCUSSION**

Microfluidization reduces MF globule size and implies a multiplication of the number of globules. According to Peters (26), the weak coagulum formed by homogenized milk is caused by the greater dispersion of the MF globules in the curd and the reduced number of free caseins available to form a strong network. The reduced surface of the casein micelles available for interaction may inhibit the syneresis rate of homogenized or, in this case, microfluidized milk (17). The higher moisture content of the resulting cheese could account for its decrease of firmness compared with that of the control (20). The weaker texture may also be caused by the new MF globules that participate in the casein network instead of being trapped within the casein matrix (31). The FDC is controlled by the ratio casein:fat of the cheese milk (20) and is related to the final cheese quality (23). For the same initial casein:fat ratio in cheese milk, FDC for treated cheeses was higher than for the control. Cheddar with a high FDC usually has a high moisture in fat-free cheese, which may decrease firmness (20). Protein content on a dry basis influences the physical texture of cheese. For the same moisture content, a higher protein content in the dry cheese results in cheese that will appear drier (23).
TABLE 6. Mean recovery coefficients for fat, protein, and casein obtained during cheese-making trials with non-microfluidized and microfluidized milks (n = 6).

<table>
<thead>
<tr>
<th>Microfluidization pressure</th>
<th>Milk 0 MPa</th>
<th>Milk 7 MPa</th>
<th>Milk 14 MPa</th>
<th>Milk 69 MPa</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>.885a</td>
<td>.957b</td>
<td>.956b</td>
<td>.972b</td>
<td>.018</td>
</tr>
<tr>
<td>Protein</td>
<td>.749a</td>
<td>.740a</td>
<td>.734a</td>
<td>.736b</td>
<td>.013</td>
</tr>
<tr>
<td>Casein</td>
<td>.970a</td>
<td>.984a</td>
<td>.985a</td>
<td>.983a</td>
<td>.028</td>
</tr>
</tbody>
</table>

\(^{a,b}\)Means within the same row with the same superscript letters are not significantly different (P > .05) based on the Scheffe test (30).

Microfluidization of the cream separated from the cheese milk followed by reconstitution of the milk did not compensate for the adverse effects of microfluidization. Separate microfluidization of cream was assumed to lower the adsorption of casein on the new MF globule membrane, making cheese milk casein more available to form a firm coagulum, as occurs in milk that is not microfluidized. When microfluidized cream was mixed with skim milk to produce a standardized cheese milk, casein may have replaced some of the whey proteins forming the new membrane. Darling and Butcher (11) observed that whey proteins are only strongly bound to the MF globule when a heat treatment (such as pasteurization) is applied to the cream after homogenization. In the present experiment, microfluidized cream was used to reconstitute cheese milk before pasteurization. Therefore, during heat treatment, caseins may have replaced part of the whey proteins on the newly formed membrane. The coagulum made from microfluidized milk and cream was more brittle and crumbly than for the control milk, which could explain the greater loss of fines in the whey of microfluidized milk and cream. More information on the composition of the new membrane by electron microscopy studies or electrophoretic analyses is necessary to confirm these visual observations.

In a solid material such as cheese, light penetrates the superficial layers and is scattered by the MF globules (6). Because microfluidization increased the number of MF globules, scattering was increased. The reflection by the pigments was similar in all cheeses, but the contribution of scattering was more important in cheeses made from microfluidized milk or cream. Therefore, treated cheeses appeared whiter during color analysis and visual evaluation.

Estimation of yield is economically important. Several factors may account for variation in yields, such as composition of milk, final composition of cheese, and cheese-making techniques, inducing fat losses during cheese processing (13). In the present study, because the milk composition and cheese-making technique were carefully controlled, the increase in yield may be attributed to the cheese composition and to cheese-making quality of milk as affected by microfluidization. For comparison, actual yield has been adjusted to constant moisture and salt, including whey solids in the cheese. Adjusted yield increased 4.3% for cheeses made from microfluidized milk or cream compared with that for control cheese. This significant increase can be explained by a better retention of MF in the microfluidized cheese than in the control, as indicated by the higher coefficients of fat recovery (Table 6) and by the lower fat losses in the whey (Table 2). However, the effect of microfluidization on commercial yield of cheese could depend on the actual plant efficiency, particularly with respect to the average MF loss to the whey.

Expression of yield on the basis of percentage of theoretical yield allows comparison of treatments of different lots of milk in properly designed experiments (12). Efficiency of yield, calculated by the ratio of adjusted:theoretical yield, is a measure of the extent of fat and casein incorporation into the cheese (23). Use of microfluidized milk and cream resulted in a greater efficiency than the control milk; values exceeded 1.00, possibly indicating that >96% of casein, 93% of MF, or both, as used in the
theoretical van Slyke formula (34), were recovered in the cheese. For control cheese, 97% of the milk casein and 88.5% of the MF were retained in the cheese; however, for microfluidized treatments, these values were 98.5 and 97.2%, respectively.

Microfluidization of milk or cream whitened Cheddar cheese but had obvious effects on texture and composition. Microfluidization of milk at 7 MPa produced better results than separate microfluidization of cream. Cheese made from this milk showed no difference in firmness, but moisture and actual yield increased approximately 7 and 8.7%, respectively, and color was significantly whiter than for cheese made from the nonhomogenized control treatment. The comparative increase in salt in the control cheese would have encouraged extra moisture loss from the control curd, accentuating the large increase in moisture retained in the experimental cheese.

When microfluidization is used in Cheddar cheese manufacturing, the cheese-making procedure should be modified to favor whey drainage and to decrease cheese moisture content. This technology would then be suitable for the production of mild Cheddar cheese with good overall quality and would increase cheese yield by about 4.3% compared with that for cheese of similar composition produced with untreated cheese milk.

CONCLUSIONS

The results of this study showed that microfluidization of cheese milk and separate microfluidization of cream produced Cheddar cheese with a whiter color and increased cheese yield. However, cheese composition and texture have been modified significantly by this treatment. Cheeses made from microfluidized cream were higher in moisture and had a softer texture. The increase of cheese yield had been assigned to a better retention of fat and moisture.

Separate microfluidization of cream did not permit resolution of the negative effects of homogenization. However, microfluidization of cheese milk at low pressure (7 MPa) could be recommended for production of good quality Cheddar cheese with higher yield.

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REFERENCES

CHEDDAR MADE FROM MICROFLUIDIZED MILK
