Reduction of Salt (NaCl) Losses During the Manufacture of Cheddar Cheese*

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ABSTRACT

The objective of this study was to evaluate the effects of cheese-making technologies, including homogenization of cream, ultrafiltration, and vacuum condensing of milk, on the retention of salt in Cheddar cheese. One part of pasteurized, separated milk (0.58% fat) was ultrafiltered (55°C, 16.0% protein), another vacuum condensed (12.5% protein), and the third was not concentrated. Cheddar cheese was manufactured using 6 treatments by standardizing unconcentrated milk to a casein-to-fat ratio of 0.74 with unhomogenized 35% fat cream (C), homogenized (6.9 MPa/3.5 MPa) 35% fat cream (CH), ultrafiltered milk and unhomogenized cream (UF), ultrafiltered milk and homogenized cream (UFH), condensed milk and unhomogenized cream (CM), and condensed milk and homogenized cream (CMH). Treatments C and CH had 3.7% fat and 3.5% protein, and the respective values for the remaining treatments were 4.9 and 4.6. The milled curd was dry salted at 2.7% by weight. The salt content of the cheeses receiving homogenization treatment was higher at 1.83 and 1.70% for CH and UFH, respectively, compared with their corresponding controls at 1.33%. The salt content in cheeses from CMH was 1.64% and was not affected by homogenization. Salt retention in C increased from 41.7 to 59.2% in CH, and in UF it increased from 42.5 to 54.5% in UFH. There was a corresponding decrease in the salt content of whey from these cheeses. (**Key words:** Cheddar cheese, homogenization, salt retention)

Abbreviation key: C = control unhomogenized treatment, CH = control homogenized treatment, CM = condensed milk with unhomogenized cream, CMH = con-

densed milk with homogenized cream, UF = ultrafiltered milk with unhomogenized cream, UFH = ultrafiltered milk with homogenized cream.

INTRODUCTION

Use of salt (sodium chloride, NaCl) as a food preservative dates to prehistoric times. Judicious use of salt in cheese improves shelf stability and adds to its flavor. Salt directly influences the properties of cheese by controlling microbial growth and activity, enzyme activities, syneresis, and texture of curd (Fox, 1993). In the manufacture of milled curd Cheddar cheese, most of the whey is drained after cooking and during cheddaring and salting. Additional whey is expelled when salted curd is pressed. This salt whey may contain 6 to 8% salt.

Approximately 10 kg of cheese is produced from 100 kg of milk. Of the remaining 90 kg, approximately 2% is salt whey. Based on Cheddar cheese production in the United States of 1.26 billion kg in 2001 (USDA, 2001), approximately 226 million kg of salt whey was generated, which amounted to a salt loss of approximately 15.9 million kg.

There are limited means available to dispose of salt whey. Salt whey cannot be drained into the municipal sewage systems because of its high biological oxygen demand/chemical oxygen demand. It is often spread on land, but this is being discouraged because of its negative impact on soil properties and the quality of nearby water bodies. Because of this negative impact, there are restrictions on land-spreading of salt whey (Wendorff, 1996). The chloride content of drinking water should not exceed 250 mg/L (USPHS, 1962). This concern for chloride toxicity has led to increased regulatory activity by the EPA to control the levels of chloride being discharged to surface water. These restrictions on the discharge of chlorides make salt whey disposal difficult for cheese plants. Sanderson et al. (1998) patented a process using nanofiltration for separating salt from salt whey. The salt solution was concentrated by evaporation and the saturated salt solution was used as a food additive. Some cheese plants use nanofiltration for separating salt and whey proteins from salt whey.

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Permeate containing salt is discharged into the waste water system and the retentate containing whey proteins is returned to the plant. The disposal of the salt whey stream continues to be a problem (Wendorff, 1996). Disposal of salt whey is therefore a major concern to cheese manufacturers. Methods for reducing the volume of salt whey or processes for utilization of salt whey are needed. The objectives of this study were to determine the effects of various cheese making technologies, i.e., homogenization of cream, ultrafiltration, and vacuum condensing of milk, on the retention of salt in Cheddar cheese. Data are provided here to demonstrate that the use of homogenized cream in Cheddar cheese manufacture would increase the retention of salt in cheese and consequently reduce waste salt.

MATERIALS AND METHODS

Milk Processing

Approximately 1000 kg of raw milk per replicate was separated at 4°C using a tri-process separator (340 ATP, De Laval Separator Co., New York, NY) into fat-reduced milk (0.58% fat) and 37%-fat cream. A new batch of raw milk was used for each replicate. The fat content of separated milk was limited by the efficiency of the cream separator. This cream was standardized to 35% fat with the fat-reduced milk, heated to 55°C, and divided into 2 parts. One part was passed through the homogenizer without any pressure. The second part was homogenized using a 2-stage homogenizer (Gaulin, Haskon Inc. Equipment Division, Lincoln Sales, St. Paul, MN) at 6.9 MPa (1000 psi) in the first stage and 3.5 MPa (500 psi) in the second stage. Both creams were then pasteurized separately at 65°C for 30 min and cooled to 4°C. The fat-reduced milk was pasteurized at 62.8°C for 30 min in a vat (P-300 to 8656, The Creamery Package Mfg. Company, Chicago, IL), cooled to 10°C, and stored at 4°C until the next step, which commenced later in the day.

Ultrafiltration and Vacuum Condensing

Approximately 182 kg of the pasteurized milk was ultrafiltered at 55°C using a spiral wound membrane of 5.6-m² surface area (model 1/1; Koch Membrane Systems Inc., Wilmington, MA) to 5 × volumetric concentration (approximately 16% protein). Total processing time per batch was approximately 45 min. The ultrafiltered milk was cooled and stored at 4°C in 38-L stainless steel cans. On the same day, approximately 182 kg of pasteurized milk at 55°C was vacuum condensed (Blaw Knox Company, Dairy Equipment Division, Mora, MN) in a single-stage rising film evaporator to obtain a 3.5 × volumetric concentration (approximately 12.5% pro-

tein). This concentrate was cooled at 4°C and stored in 38-L cans. Total processing time per batch was approximately 1 h. Cheese making began the next day.

Cheese Manufacture

Two randomly selected treatments of cheese were made per day in two 250-kg cheese vats (4 MX model 65, Kusel Equipment Co., Watertown, WI) the day after processing. One replicate of cheese making (6 treatments) was completed over a 3-d period. Cheese milk was standardized on the day of manufacture with the above creams, concentrates, and milk to casein to fat ratio of 0.74 to 0.76. The treatments were unconcentrated milk that was standardized with either unhomogenized 35%-fat cream (C), homogenized 35%-fat cream (CH), ultrafiltered milk and unhomogenized cream (UF), ultrafiltered milk and homogenized cream (UFH), condensed milk and unhomogenized cream (CM), or condensed milk and homogenized cream (CMH).

For C and CH, 90.8 kg of cheese milk was used, whereas for the rest of the treatments, 73.8 kg of cheese milk was used. Cheese milk at 31°C was inoculated with frozen concentrated DVS mesophilic lactic starter culture (M61, Marschall Superstart, Rhodia Inc., Madison, WI) at 7 g/kg protein. After 30 min of ripening, rennet (Chymostar Classic, Rhodia Inc.) was added at 20 mL/100 kg to C and CH and 14 mL/100 kg to UF, UFH, CM, and CMH. The rennet was diluted 40× with distilled water and mixed with milk thoroughly (Oomen et al., 2000). When the curd was firm, it was cut using horizontal and vertical wire knives of 0.64-cm width and allowed to heal for 15 min. The mixture was gradually heated to 36°C for UF, 37°C for C and CM, 38°C for UFH and CMH, and 39°C for CH within 30 min, and held at that temperature for another 30 min. Whey was collected in 38-L stainless steel cans. Cook temperatures varied among treatments to ensure similar moisture content. During cheddaring, curd was turned every 15 min to a final pH of 5.2 before milling. The whey released during cheddaring was mixed with the whey collected earlier and a representative sample was drawn for further analysis. Milled curd was salted (Morton International Inc., Chicago, IL) at the rate of 2.7% by weight of curd. Salt was applied in the dry form in 3 equal portions with 3 min stirring between applications. Whey generated during salting and pressing was collected and labeled as salt whey. Salted curd was hooped in a 9-kg rectangular cheese-hoop, placed in polyethylene bags, and pressed (AFVS-Spec, Kusel Equipment Co., Watertown, WI) for 15 to 17 h at 2.8 kg/cm² (40 psi). Whey collected in the polyethylene bags after pressing was blended with the above salt whey

and weighed. The cheese blocks were removed, weighed, vacuum packaged (model 620A, Sipromac, St. Germain, Canada) in Cryovac bags (Cryovac Division, W. R. Grace and Co., Duncan, SC), dipped in hot water for a few seconds, placed in a curing room at 4°C, and sampled after 1 wk.

Samples of fat-reduced milk, cream, and ultrafiltered and condensed milks were taken after cooling. Cheese milk for each treatment was taken directly from the vat prior to the addition of starter. Whey obtained during draining and cheddaring was weighed and pooled before a sample was taken. Whey generated during salting and pressing was weighed and pooled and, from this mixture, a sample of salt whey was drawn. After 1 wk, a 1-kg block of cheese was cut, shredded, and mixed, and a sample was taken for analysis.

Analysis

Composition. For cheese milk standardization, cream, fat-reduced milk, ultrafiltered milk, and condensed milk were analyzed for fat using the Mojonnier method (995.19, AOAC, 2000; Atherton and Newlander, 1977). Protein for cream was analyzed by the Kjeldahl method (Atherton and Newlander, 1977). Protein in fat-reduced milk, retentate, and condensed milk was analyzed using an infrared instrument (Milkoscan, FOSS North America Inc., Eden Prairie, MN). The casein content of milk was assumed to be 75% of the total milk protein content. The infrared analysis was done to obtain rapid measurements for standardization of milk on the same day as processing. Subsequently, the Kjeldahl method was used for protein analysis of all standardized milks and yield analysis.

After standardization was completed, fat and protein in all samples were analyzed using the Mojonnier and Kjeldahl methods as above. Total protein was determined by multiplying total nitrogen obtained by the macro Kjeldahl method (Atherton and Newlander, 1977) by a factor of 6.38. Casein in milk was determined using Rowland's procedure (Rowland, 1938). Ash was determined using a muffle furnace at 535°C (935.42, AOAC, 2000) and total solids or moisture in an atmospheric oven (Fisher Econotemp, Laboratory Oven model 30 G) at 100°C (Kosikowski and Mistry, 1997). Salt and calcium were determined using the atomic absorption method (990.23, AOAC, 2000) (model 500, Perkin-Elmer Analytical Instruments, Oak Brook, IL). Sodium chloride was calculated from sodium using a factor of 2.54. The pH of cheese at 1 d and 1 wk was measured using a Corning pH meter (model 320, Corning Inc., Corning, NY) by inserting a spear-tip electrode into the cheese.

Mass balance. Mass balance, as well as fat, protein, and salt balance, for all treatments and all replications was performed. Weights of all ingredients added to cheese milk, i.e., starter, rennet solution, and salt, were recorded. The weight of the sample drawn for analysis was subtracted from the total cheese milk in the vat. The fat, protein, and salt recoveries in cheese were determined as follows (Metzger and Mistry, 1994):

$$\text{Recovery, \%} = (\text{weight of component in cheese, kg}) \div (\text{weight of component in cheese milk, kg}) \times 100.$$

Cheese yield. When new cheese-making procedures are proposed, the impact of the procedure on cheese yield must be revisited.

Actual cheese yield in this study was expressed as the amount of cheese after pressing from 100 kg of milk. The actual yield was adjusted to 37% moisture and 1.5% salt in cheese as follows: actual yield $\times [(100 - (\text{actual percentages of moisture and salt}) \div (100 - (\text{desired percentages of moisture and salt}))] \div \text{percentage protein in milk}$ to determine quantity of cheese per unit protein in treatments (Metzger and Mistry, 1994):

$$\text{Adjusted yield/kg protein} = \text{adjusted yield} \div \% \text{ protein in milk.}$$

Predicted yield was calculated using a modified Van Slyke and Publow formula (Emmons and Lacroix, 2000; Mistry et al., 2002):

$$\text{Yield, \%} = [(F \times R_f + C - 0.1) \times 1.016] \div (1 - SC - M \div (1 - WS)),$$

where F and C are the percentage of fat and percentage of casein in milk, respectively, R_f is the percentage of fat in milk recovered in cheese $\div 100$, SC is the percentage of salt in cheese $\div 100$, M is the percentage of moisture in cheese $\div 100$, and WS is the percentage of solids in whey $\div 100$. The values used were the average of 5 replications, i.e., the treatment means.

Actual cheese yield was adjusted stepwise for moisture and salt first, followed by casein and fat, and finally fat recovery as follows (Emmons, 1995):

$$Y_{\text{adj}} = Y_{\text{act}} \times PY_{\text{adj}} \div PY_{\text{act}},$$

where Y_{adj} = adjusted yield, Y_{act} = actual yield, PY_{adj} = predicted yield where only the components to be adjusted are changed to target values, and PY_{act} = predicted yield where actual values are used. Target values were experiment means: 4.52% fat in milk, 3.38% casein in milk, 36.9% moisture in cheese, 1.57% salt in cheese,

Table 1. Statistical model used for the data analysis of salt losses, component recoveries in cheese, and yield of cheese.

Source of variation	Degrees of freedom
Replications, <i>r</i>	(<i>r</i> -1) = 4
Concentration treatment ¹	(<i>t</i> -1) = 2
Homogenization, <i>h</i>	(<i>h</i> -1) = 1
Treatment × homogenization (<i>t</i> × <i>h</i>)	(<i>c</i> -1) (<i>h</i> -1) = 2
Error, <i>r</i> × <i>t</i> × <i>h</i>	(<i>r</i> -1) (<i>ch</i> -1) = 20
Total	(<i>rch</i> -1) = 29

¹ Control, ultrafiltration, and condensing.

92.93% fat recovery in cheese, and 8.29% total solids in whey.

Statistical Analysis

The experiment was a split-plot design. The experiment was conducted using 5 blocks (replications). Each block was divided into 3 parts—control, ultrafiltration, and vacuum condensing—and these 3 levels were randomly assigned as whole plot units. Each whole plot unit consisted of 2 plots: one with homogenization and the other without. PROC MIXED of the SAS software was used to analyze the data for composition and yield. The least square means were separated at 95% level of significance (SAS, 1990). Table 1 shows the statistical model used.

RESULTS AND DISCUSSION

Composition of Cheese Milk

Homogenization had no impact on the composition of the milks (Table 2). The average fat and protein for the control treatments (C and CH) were 3.72 and 3.51%, respectively. The protein content of milk was higher than average partly because the milk was a mixture of Holstein and Brown Swiss and in part because of the feeding regimen. The fat and protein in cheese milk containing concentrates (UF, UFH, CM, and CMH) were 4.92 and 4.60%, respectively. The ratio of casein to fat averaged 0.74 and that of casein to total protein averaged 0.80. The net result of standardization was that for C, CH, UF, UFH, CM, and CMH the percentage of total fat coming from cream was similar, 86.1, 86, 84.8, 84.8, 85.7, and 85.7%, respectively. With a cream separator of better separation efficiency, the contribution of fat from cream could be higher.

Characteristics of Cheese Making and Composition of Cheese

As expected, homogenization of cream increased its viscosity, but it did not present any difficulty in mixing it with milk. Cheese milk prepared with homogenized cream showed minimal fat floating on the surface compared with cheese milk prepared with unhomogenized

Table 2. Composition¹ of cheese milk and Cheddar cheese.

	Treatment ²						
Component	C	CH	UF	UFH	CM	CMH	SEM
	(%)						
Cheese milk							
Total solids	12.99	13.11	15.09	15.11	16.93	17.21	0.312
Fat	3.72	3.71	4.93	4.92	4.92	4.92	0.107
Protein ³	3.51	3.52	4.60	4.60	4.60	4.60	0.097
Casein ⁴	2.81	2.83	3.66	3.69	3.63	3.64	0.080
Cheddar Cheese							
Moisture	37.37 ^b	38.35 ^a	35.99 ^c	36.90 ^b	35.68 ^c	37.13 ^b	0.322
Fat	33.39 ^a	33.32 ^a	33.85 ^a	33.39 ^a	33.21 ^a	33.71 ^a	0.149
Protein ³	24.97 ^a	24.00 ^c	25.49 ^{ab}	24.30 ^c	24.21 ^c	24.36 ^{bc}	0.142
Salt	1.33 ^c	1.83 ^a	1.33 ^c	1.70 ^b	1.62 ^b	1.64 ^b	0.037
Ash	3.30 ^d	3.62 ^b	3.46 ^c	3.64 ^{ab}	3.76 ^a	3.75 ^{ab}	0.034
Calcium	0.66 ^{cd}	0.62 ^e	0.70 ^a	0.65 ^d	0.69 ^{ab}	0.67 ^{bc}	0.007
Ca:protein	0.0264 ^c	0.0258 ^d	0.0273 ^b	0.0266 ^c	0.0285 ^a	0.0275 ^b	0.0003
pH at 1 d	5.00	5.05	4.96	5.02	5.02	4.99	0.013

^{a,b,c,d,e}Means in a row without common superscript differ ($P \leq 0.05$).

¹Means of 5 replicates.

²Treatment: C = Control, cheese milk with unhomogenized cream; CH = Control, cheese milk with homogenized cream at 6.9/3.5 MPa; UF = cheese milk with unhomogenized cream and ultrafiltered milk; UFH = cheese milk with homogenized cream and ultrafiltered milk; CM = cheese milk with unhomogenized cream and condensed milk; and CMH = cheese milk with homogenized cream and condensed milk.

³Protein = Total nitrogen × 6.38.

⁴Casein = (Total nitrogen – noncasein nitrogen) × 6.38.

Table 3. Composition¹ of cheese whey and salt whey.

	Treatment ²						SEM
	C	CH	UF	UFH	CM	CMH	
	(%)						
Cheese whey							
Total solids	7.47 ^d	7.31 ^e	7.79 ^c	7.60 ^d	9.83 ^a	9.70 ^b	0.199
Fat	0.27 ^b	0.16 ^d	0.35 ^a	0.22 ^c	0.35 ^a	0.24 ^{bc}	0.014
Protein ³	0.93 ^d	0.91 ^d	1.21 ^b	1.15 ^c	1.28 ^a	1.25 ^{ab}	0.029
Ash	0.50 ^d	0.53 ^{bcd}	0.52 ^c	0.56 ^b	0.68 ^a	0.69 ^a	0.015
Salt whey							
Total solids	16.08 ^c	15.80 ^c	16.17 ^{bc}	15.59 ^c	17.08 ^{ab}	17.34 ^a	0.166
Fat	1.34 ^a	0.59 ^c	0.92 ^b	0.57 ^c	0.55 ^c	0.39 ^d	0.074
Protein ³	1.23 ^{bc}	1.18 ^c	1.41 ^a	1.34 ^{ab}	1.46 ^a	1.40 ^a	0.025
Salt	7.84 ^b	6.27 ^d	9.00 ^a	7.11 ^{bc}	7.07 ^{bcd}	6.89 ^{cd}	0.200
Ash	8.73 ^b	6.99 ^d	10.22 ^a	8.10 ^{bc}	8.18 ^{bc}	7.72 ^c	0.222

a,b,c,d,e Means in a row without common superscript differ ($P \leq 0.05$).

¹Means of 5 replicates.

²Treatment: C = Control, cheese milk with unhomogenized cream; CH = Control, cheese milk with homogenized cream at 6.9/3.5 MPa; UF = cheese milk with unhomogenized cream and ultrafiltered milk; UFH = cheese milk with homogenized cream and ultrafiltered milk; CM = cheese milk with unhomogenized cream and condensed milk; and CMH = cheese milk with homogenized cream and condensed milk.

³Protein = Total nitrogen $\times$ 6.38.

cream. It had been observed that homogenization of milk for cheese making leads to curd shattering (Peters, 1956; Rao, 1985). However, when homogenized cream was used to standardize milk, this defect was not observed. This treatment of cheese resulted in cheese with no surface fat on the cheese after pressing. More surface fat was noted for the control cheeses. Curds from concentrates, especially those from condensed milk, shattered during salting and expelled less whey compared with the control treatments.

Cheeses with homogenized cream had higher moisture than the corresponding cheeses with unhomogenized cream (C vs. CH; UF vs. UFH; and CM vs. CMH). Cheeses made with concentrates had lower moisture even though the cooking temperature was lowered (Table 2). Cheddar cheese from CH had the highest moisture, and those from CM and UF had the lowest. The higher moisture in homogenized-cream cheeses may be due to the increased resistance of water flow due to small fat globules, resulting in less shrinkage of the curd network (Walstra et al., 1985). The fat content of cheese was similar for all treatments ($P \geq 0.05$). The protein content of cheeses varied from 24.00 to 25.49%. The ash content of cheese varied from 3.30 to 3.76%. Cheese from CH and UFH had higher ash than their corresponding unhomogenized controls. Homogenization had no impact on the ash content of condensed milk cheeses. This difference in ash content between homogenized and unhomogenized treatments may be due to the higher salt content of cheeses with homogenized cream. The calcium content of these cheeses was lower compared with the unhomogenized treatments. This may suggest a partial replacement of calcium by

sodium ions in the case of treatments with homogenized cream, thereby increasing their salt content.

The salt content of cheese varied from 1.33 to 1.83% (Table 2). Treatments with homogenized cream had higher ($P \leq 0.05$) salt than those with unhomogenized cream. This was not observed in treatments involving condensed milk. This may be caused by a partial replacement of calcium in cheese by sodium or by lower syneresis in the homogenized treatments (Nair et al., 2000) or because of the hindrance to the flow of salt whey in the protein matrix of cheese interspersed with fine fat globules. Homogenization had no impact on the salt content of condensed milk cheeses. The salt content of condensed milk cheeses from unhomogenized cream was higher than C and UF cheeses. This effect may be due to the partial homogenization of residual fat due to vigorous boiling under vacuum during condensing (Mabbitt and Cheeseman, 1967) coupled with the small particle size of residual fat in the fat reduced milk. The pH at draining and pH at d 1 was similar for all treatments.

Composition of Cheddar Cheese Whey

The total solids in whey increased as the total solids in cheese milk were raised. However, the total solids in whey were lower for treatments with homogenized cream (Table 3). Fat and protein content of whey increased ($P \leq 0.05$) with the increase in protein concentration in milk (Table 3). This is in part due to the concomitant decrease in the volume of whey expressed per unit of milk (Guinee et al., 1996). For a given treatment, the fat content of whey decreased with homogeni-

Table 4. Mass and component recovery¹ in Cheddar cheese as influenced by homogenized cream.

Recovery	Treatment ²						SEM
	C	CH	UF	UFH	CM	CMH	
	(%)						
Mass recovery							
Total weight ³	98.09 ^{ab}	98.27 ^a	97.77 ^{bc}	97.81 ^{bc}	97.76 ^c	97.77 ^{bc}	0.076
Cheese	9.83 ^e	10.55 ^d	12.88 ^c	13.95 ^a	13.50 ^b	13.90 ^a	0.310
Whey	86.18 ^a	86.01 ^b	82.46 ^c	81.35 ^e	81.72 ^d	81.27 ^e	0.418
Salt whey	2.08 ^d	1.71 ^e	2.43 ^c	2.51 ^b	2.54 ^b	2.60 ^a	0.082
Salt recovery							
Cheese ⁴	41.67 ^d	59.24 ^a	42.54 ^d	54.48 ^b	51.54 ^c	52.26 ^{bc}	1.306
Salt whey ⁴	50.84 ^a	33.66 ^c	53.64 ^a	41.34 ^b	41.78 ^b	41.77 ^b	1.351
Total ⁵	92.51	92.90	96.18	95.82	93.32	94.03	1.406
Fat recovery							
Cheese ⁴	89.40 ^c	95.84 ^a	89.33 ^c	95.47 ^a	91.97 ^b	95.59 ^a	0.544
Whey ⁴	6.30 ^a	3.80 ^b	5.94 ^a	3.75 ^b	5.81 ^a	3.96 ^b	0.226
Salt whey ⁴	0.76 ^a	0.28 ^c	0.46 ^b	0.30 ^c	0.28 ^c	0.21 ^c	0.044
Total ⁵	96.46	99.92	95.73	99.52	98.06	99.77	0.632
Protein ⁶ recovery							
Cheese ⁴	70.76 ^e	72.83 ^{bc}	72.00 ^{cd}	74.19 ^a	71.54 ^{de}	73.77 ^{ab}	0.309
Whey ⁴	23.14 ^a	22.55 ^a	21.96 ^a	20.41 ^b	22.87 ^a	22.26 ^a	0.246
Salt whey ⁴	0.74 ^a	0.58 ^b	0.75 ^a	0.74 ^a	0.81 ^a	0.80 ^a	0.025
Total ⁵	94.64	95.96	94.71	95.34	95.22	96.83	0.544

a,b,c,d,e Means in a row without common subscript differ ($P \leq 0.05$).

¹Means of 5 replicates.

²Treatment: C = Control, cheese milk with unhomogenized cream; CH = Control, cheese milk with homogenized cream at 6.9/3.5 MPa; UF = cheese milk with unhomogenized cream and ultrafiltered milk; UFH = cheese milk with homogenized cream and ultrafiltered milk; CM = cheese milk with unhomogenized cream and condensed milk; and CMH = cheese milk with homogenized cream and condensed milk.

³Mass recovered per mass utilized.

⁴Component recovered in cheese, whey, or salt whey per component in cheese milk.

⁵Sum of components recovered in cheese, whey, and salt whey per component in cheese milk.

⁶Protein = Total nitrogen $\times$ 6.38.

zation (C vs. CH; UF vs. UFH; and CM vs. CMH), whereas protein reduction was significant only for the ultrafiltration treatment. Homogenization was reported to reduce the fat content of whey (Rao, 1985; Metzger and Mistry, 1994; Nair et al., 2000; Oommen et al., 2000).

Composition of Salt Whey

The total solids content of salt whey increased with protein concentration in cheese milk and was not affected by homogenization. The fat content of salt whey decreased significantly as the total protein in cheese milk was increased (Table 3). Salt whey from CMH had the lowest fat. Homogenization also reduced the fat in salt whey but not protein. Both homogenization and concentration had a significant effect on the level of salt and ash in salt whey. Ash in salt whey increased with total protein in milk but decreased in whey from CH and UFH, an effect of homogenization. This effect was not noted for the condensed milk treatments. As a result of homogenization of cream, the salt content of salt whey was lower compared with those with unhomogenized cream.

Component Recovery

The average mass balance for the 6 treatments across 5 replicates was 97.82%, i.e., 97.82% of the total mass used was accounted for (Table 4). The remaining 2.18% reflects losses due to curd fines, evaporation, and materials adhering to cheese-making equipment. Mass balance for homogenized treatments was similar to unhomogenized treatments but slightly higher in controls than in concentrates. This may be due to higher losses of curd fines in whey for concentrates.

Salt recovery in cheese increased ($P \leq 0.05$) with homogenization for control and ultrafiltration treatments (Table 4). This may be because of reduced syneresis during salting and pressing in homogenized cream treatments or greater resistance to the movement of sodium chloride in the protein-fat matrix during pressing. Pore sizes in the protein matrix may be larger with higher moisture in cheese and thus reduce frictional effect of inward-diffusing salt (Wendorff and Johnson, 1991). In the unconcentrated milk, homogenization of cream increased salt recovery in cheese from 41.67% in C to 59.24% in CH. Salt recovery was not affected by ultrafiltration, but when ultrafiltration was combined

Table 5. Effect of homogenization of cream on yield of Cheddar cheese.¹

Type of yield	Treatment ²						SEM
	C	CH	UF	UFH	CM	CMH	
	kg/100 kg milk						
Actual	9.83 ^c	10.55 ^d	12.88 ^c	13.95 ^a	13.50 ^b	13.90 ^a	0.310
Adjusted							
per kg protein ³	2.79 ^c	2.92 ^{bc}	2.85 ^c	3.02 ^a	2.99 ^{ab}	2.99 ^{ab}	0.038
M, S ⁴	10.38 ^e	10.80 ^d	13.84 ^c	14.40 ^{ab}	14.21 ^{bc}	14.52 ^a	0.329
M, S, Cs, F ⁴	12.70 ^c	13.19 ^b	12.73 ^c	13.19 ^b	13.14 ^b	13.42 ^a	0.049
M, S, Cs, F, R _f ⁴	12.98 ^b	12.97 ^b	13.01 ^b	13.00 ^b	13.22 ^a	13.20 ^a	0.019

a,b,c,d,e Means in a row without common superscript differ ($P \leq 0.05$).

¹ Means of 5 replicates.

² Treatment: C = Control, cheese milk with unhomogenized cream; CH = Control, cheese milk with homogenized cream at 6.9/3.5 MPa; UF = cheese milk with unhomogenized cream and ultrafiltered milk; UFH = cheese milk with homogenized cream and ultrafiltered milk; CM = cheese milk with unhomogenized cream and condensed milk; and CMH = cheese milk with homogenized cream and condensed milk.

³ Actual yield adjusted for moisture (37%) and salt (1.5%): actual yield $\times [(100 - (\text{actual percentages of moisture and salt}) \div (100 - (\text{desired percentages of moisture and salt}))]$.

⁴ Based on modified Van Slyke and Publow formula
Yield, % = $[(F \times R_f + Cs - 0.1) \times 1.016] \div (1 - S - M + (1 - WS))$,
where F and Cs are the percentage fat and percentage casein in milk respectively, R_f is the percent of fat in milk recovered in cheese $\div 100$, S is the percentage salt in cheese $\div 100$, M is the percentage moisture in cheese $\div 100$, and WS is the percentage solids in whey $\div 100$.

with homogenization, it increased from 42.54% in UF to 54.48% in UFH (Table 4). For condensed milk cheeses, the impact of homogenization on salt recovery in cheese was minimal (2.9%). However, it is important to note that salt recovery in condensed milk cheeses without homogenization (CM) was higher than in the control cheese (C) (Table 4). This increase of salt recovery in cheese with homogenization can have a big impact in commercial cheese plants. For a plant handling a million kilograms of milk daily, the savings in salt due to homogenization would be approximately 635 kg.

The impact of homogenization on fat recovery in cheese is known (Peters, 1956; Metzger and Mistry, 1994; Nair et al., 2000; Oommen et al., 2000). In the current study, fat recovery in cheese increased ($P \leq 0.05$) with homogenization but was not affected by ultrafiltration. Homogenization could have induced better entrapment of fat globules in the protein network. Protein recovery increased with homogenization, and this increase was also affected by higher solids in cheese milk. It is likely that homogenization of cream increases the surface area of fat globules on which serum phase proteins are adsorbed or bound, resulting in a stronger protein-protein interaction.

Cheese Yield

The actual yield of cheese increased with homogenization and concentration; treatments UFH and CMH had the highest actual yields (Table 5). Higher actual yields for homogenized treatments were due to higher fat, protein, and salt recovery.

Moisture and salt adjusted yield per kilogram protein in milk increased with concentration (Table 5). It also increased with homogenization because of increased casein recovery except for condensed milk treatments. As the yields were adjusted for different components, the differences in yield due to homogenization were lower, but the concentrates still had higher yields. When adjustment of moisture and salt was done, yield of homogenized treatment cheeses remained high ($P \leq 0.05$). In a subsequent adjustment for milk casein and fat, yields of condensed milk treatments were higher compared with ultrafiltered milk and control cheeses. Yield in homogenized treatments was still higher ($P \leq 0.05$). When yield was adjusted for fat recovery along with the previous 4 factors, the yield of condensed milk treatments was higher and the difference between homogenization and nonhomogenization diminished. The increase in yield can be attributed to condensing and increased fat recovery to homogenization.

The cause for an increase in salt retention in cheeses made with homogenized cream is of interest and needs to be studied further. It may be caused by differences in the physico-chemical characteristics of the curd matrix imposed by these treatments.

CONCLUSIONS

This study has demonstrated that use of homogenized cream in Cheddar cheese manufacture increased the salt retention in cheese while increasing yield because of higher fat and protein recovery. Homogenization along with ultrafiltration also increased the salt

retention. Condensing increased the salt retention, but when combined with homogenization the increase was not significant. Increased salt retention due to homogenization may be because of the reduced rate of diffusion of salt during the pressing of cheese. It may also be due to the presence of a large number of small fat globules, which serve as an obstruction to the path of salt. Homogenization of cream in cheese making can be used as a means to decrease the salt lost in whey and thereby reduce the amount of salt whey generated. Also, there was an increase in the fat recovery in cheese with homogenization of cream.

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