Reduced-Fat Cheddar Cheese Manufactured Using a Novel Fat Removal Process*

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ABSTRACT

Normally, reduced-fat Cheddar cheese is made by removal of fat from milk prior to cheese making. Typical aged flavor may not develop when 50% reduced-fat Cheddar cheese is produced by this approach. Moreover, the texture of the reduced-fat cheeses produced by the current method may often be hard and rubbery. Previous researchers have demonstrated that aged Cheddar cheese flavor intensity resides in the water-soluble fraction. Therefore, we investigated the feasibility of fat removal after the aging of Cheddar cheese. We hypothesized the typical aged cheese flavor would remain with the cheese following fat removal. A physical process for the removal of fat from full-fat aged Cheddar cheese was developed. The efficiency of fat removal at various temperatures, gravitational forces, and for various durations of applied forces was determined. Temperature had the greatest effect on the removal of fat. Gravitational force and the duration of applied force were less important at higher temperatures. A positive linear relationship between temperature and fat removal was observed from 20 to 33°C. Conditions of 30°C and $23,500 \times g$ for 5 min removed 50% of the fat. The removed fat had some aroma but little or no taste. The fatty acid composition, triglyceride molecular weight distribution, and melting profile of the fat retained in the reduced-fat cheeses were all consistent with a slight increase in the proportion of saturated fat relative to the full-fat cheeses. The process of fat removal decreased the grams of saturated fat per serving of cheese from 6.30 to 3.11 g. The flavor intensity of the reduced-fat cheeses were at least as intense as the full-fat cheeses.

(Key words: Cheddar cheese, fat removal, reduced fat)

Abbreviation key: DAF = duration of applied force, DSC = differential scanning calorimeter, FAME = fatty acid methyl ester, GF = gravitational force, TA = titratable acidity, WSF = water-soluble fraction.

INTRODUCTION

Current processes to manufacture reduced-fat Cheddar cheese typically start with low- or reduced-fat milk and usually produce a higher moisture cheese. As fat content of Cheddar cheese decreases, textural (Bryant et al., 1995) and flavor (Banks et al., 1989) qualities become very different from full-fat Cheddar and less desirable. In an attempt to soften the hard, rubbery texture of reduced-fat cheese, the cheese moisture is increased. Visser (1991) proposed that the texture and rheological behavior of cheese could be explained by using a filled-gel composite model. With respect to Cheddar cheese structure, casein forms a gel that holds filler (i.e., moisture and fat). Reducing the fat or moisture portion of the filler volume when reducing total filler volume results in a firmer composite. Increasing the fat or moisture portion of the filler volume when increasing total filler volume softens the composite (Visser, 1991). Bryant et al. (1995) studied the effect of fat content on Cheddar cheese hardness using cheeses with 34, 32, 27, 21, and 13% fat. The total moisture content increased 38.5, 39.7, 40.8, 40.8, and 44.7% with decreasing fat content, while total filler volume decreased with decreasing fat content 72.5, 71.7, 67.8, 61.8, and 57.7%, respectively. Bryant et al. (1995) reported that the hardness scores by trained judges significantly increased with decreasing fat content. Evidently, increasing the moisture content of reduced-fat cheeses by the amount reported by Bryant et al. (1995) did not solve textural problems completely. Moreover, the apparent textural benefit associated with increasing cheese moisture may be overshadowed by the flavor problems associated with raising moisture levels of reduced-fat cheese.

Johnson et al. (2001) reported that when a firmer coagulum was used to increase reduced-fat cheese moisture, the cheese has a more mild flavor and slight bitterness after 6 mo compared with a cheese made with a

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less firm coagulum. Banks et al. (1989) reported that reduced-fat Cheddar cheeses with 16.8 and 25.6% fat, received significantly lower flavor quality and overall acceptability scores compared with a 33.1% fat cheese. Not much has changed since 1969 when Ohren and Tuckey (1969) reported similar results with reduced-fat cheeses manufactured using low-fat milk.

Consumer preferences have changed in the last 30 yr. Consumers are concerned about the impact of their diet on long-term health. A recent study reported that 41% of all shoppers are themselves or have someone in their household controlling fat intake (National Marketing Institute, 2000; Sloan, 2001). A 1997 study indicated that certain groups of consumers would increase their consumption of cheese if great tasting reduced-fat products were available (Dairy Management Inc., 1997; Gorski, 1998). In the United States, Cheddar cheese varieties account for the largest proportion of aged cheese sales, while Mozzarella cheese is the major nonaged cheese consumed (National Cheese Institute, 2000). Therefore, there is a need for great tasting reduced-fat Cheddar cheese without the common textural and flavor defects associated with these products.

How important is fat to the flavor of aged Cheddar cheese? A study by McGugan et al. (1979) addressed this question. The researchers fractionated mild and aged Cheddar cheese. There were 4 cheese fractions. A defatted bland cheese residue, a water-extract, and fat either deodorized or undeodorized were recombined from mild and aged cheeses so that the contribution of each fraction to flavor intensity could be determined. McGugan et al. (1979) concluded that the water extract contained the flavor intensity of the aged Cheddar cheeses and that the fat contributed little to the flavor intensity of the cheese. Following this study, the compounds found in the water-soluble fraction (WSF) of Cheddar cheese have been more fully characterized (Lau et al., 1991; Cliffe et al., 1993; Engles and Visser, 1994; Singh et al., 1997).

Therefore, our hypothesis was that removing fat from full-fat Cheddar cheese after it has aged and the flavor has developed will produce a reduced fat Cheddar cheese with flavor intensity similar to the original full-fat cheese because Cheddar flavor intensity is in the WSF. The goal of this research was to develop a physical process to remove fat from aged Cheddar cheese, and then determine the impact of fat removal on the characteristics of cheese fat and cheese flavor intensity. The fat removal process parameters of cheese temperature, centrifugal or gravitational force (GF), and the duration of applied force (DAF) were optimized. Once the process was optimized, the impact of fat removal on the characteristics of the cheese fat (i.e., fatty acid and triglyceride composition; and thermal properties) was measured.

Finally, the flavor intensity of reduced-fat aged Cheddar cheese, produced by fat removal from aged full-fat Cheddar, was compared to full-fat Cheddar cheese.

MATERIALS AND METHODS

Optimization of Fat Removal Process

Optimizing temperature, GF, and DAF for fat removal. Commercial Cheddar cheese aged at least 6 mo was purchased in 0.9-kg blocks. The blocks of cheese were shredded with a KitchenAid food processor equipped with a 2-mm shredding blade (model KFP6000B; KitchenAid, St. Joseph, MI). The shredded cheese was portioned into 250-mL polypropylene oak-ridge centrifuge tubes with screw top caps (Kendro Laboratory Products, Newtown, CT). Each tube contained approximately 60 g of shredded cheese. All tubes were held at 4°C prior to tempering in a water bath set to achieve a cheese temperature of 20, 25, or 30°C. When the cheese reached the target temperature, the tubes were placed in a GSA rotor (Sorvall Inc., Newtown, CT) positioned in a Sorvall RC2-B Superspeed centrifuge. Cheese at each temperature was subjected to a GF (g max) of 2126, 6300, or 23,500 $\times g$ for either 5, 10, or 20 min. After centrifugation the liquid fat was decanted from each centrifuge tube, the weight of the cheese residue was recorded, and the weight of the fat removed was calculated. The result was expressed as percent fat removed, which was calculated using the equation below:

% fat removed =

$$\frac{\text{weight of fat removed from full-fat cheese}}{\text{weight of fat in full-fat cheese}} \times 100\%$$

Further definition of the temperature effect. Fat removal over a greater range and more temperature increments than in the first phase of this work was conducted. The same methods for shredding and tempering were used to prepare the cheese for centrifugation. Cheese was tempered to 20, 22, 24, 28, 30, or 32°C and centrifuged at (g max) 23,500 $\times g$ for 5 min. After centrifugation the liquid fat was decanted.

Cheese Composition, pH, and Titratable Acidity

The fat content of the full-fat Cheddar cheese was determined by Babcock method [(Marshall, 1992); method number 15.8.A] and the fat content of the reduced-fat cheese was determined by the same method but with an additional 2 mL of Babcock acid for better digestion. Cheese moisture was determined gravimetrically by drying in a forced-air oven at 100°C for 24 h

[(AOAC, 2000); 33.2.44, method number 990.20] using a 2-g test portion. Salt content was determined using the Volhard method [(Marshall, 1992); method number 15.5.B]. The Kjeldahl method using a 1-g cheese sample was used to determine the total nitrogen (Lynch et al., 2002). The pH 4.6, and 12% TCA soluble nitrogen fractions were prepared as described by Bynum and Barbano (1985), and nitrogen was as determined [(AOAC, 2002); 33.2.11, method number 991.20]. Cheese pH was determined using a Xerolyt combination electrode (model HA405; Mettler Toledo, Columbus, OH) and an Accumet pH meter (model 915, Fisher Scientific, Springfield, NJ) after tempering to 20°C. Titratable acidity (TA) [(AOAC, 2000); method number 33.7.14, 920.124] of the cheese was determined as described by Lau et al. (1991). All analyses were carried out in duplicate except total nitrogen, which was performed in triplicate.

Fatty Acid, Triglyceride, and Thermal Analysis

Fat preparation. Three aged full-fat Cheddar cheeses, 2 commercial, and 1 manufactured at the Cornell Food Processing and Development Laboratory, were used to produce three ~50% reduced-fat cheeses. Reduced-fat cheeses were produced using fat removal with a force (g max) $23,500 \times g$ for 5 min and a cheese temperature of 30°C. Water was added before pressing to achieve a final moisture of approximately 48%. Approximately 7 kg of 50% fat reduced Cheddar was produced from each of the 3 cheeses. The full-fat cheese, reduced-fat cheese, and fat removed from full-fat cheese underwent ether extraction [(AOAC, 2000); 33.2.26, method number 989.05] using 1 g of cheese and 9 mL of distilled water instead of 10 mL of milk. The fat from the extraction of two 1-g full-fat cheese test portions was pooled and placed in 30 mL of chloroform. Likewise, fat from four 1-g test portions of the 50% fat reduced cheese was pooled and placed in 30 mL of chloroform. Two 0.33-g test portions of removed fat from each cheese were used in ether extraction and pooled after the ether extraction. Pooling of the fat was done in order to achieve similar concentrations of fat in the chloroform:lipid (approximately 22 g of fat/L) mixture of full and reduced-fat samples. The chloroform:lipid mixture was stored at -15°C in darkness until analysis.

Fatty acid methylation. A 0.5-mL portion of the chloroform:lipid mixture was placed into a 25-mL 14/20 standard taper pear shaped flask warmed with 40°C water. A stream of dry nitrogen was used to evaporate the chloroform leaving approximately 0.011 g of fat in the flask. After the chloroform evaporated, the fat was saponified and methylated (Barbano and Sherbon, 1980; Lynch et al. 1992). Two milliliters of 0.5 N metha-

nolic potassium hydroxide was immediately added, and the flask was attached to a 200-mm refluxing condenser. The flask was lowered into a 100°C sand bath and contents were allowed to boil and reflux for 6 min before 2 mL of 12% methanolic boron trifluoride was added through the top of the condenser. After 2 min of boiling, 4.8 mL of hexane was added through the top of the condenser and allowed to boil for 1 min. The flask was raised out of the sand bath, detached from the condenser, and 6 mL of room temperature saturated sodium chloride solution was added, and the flask was stoppered with a 14/20 standard taper ground glass stopper. After vortexing for 10 s, the flask was allowed to set at room temperature until the aqueous and hexane layers separated (approximately 10 min). Saturated sodium chloride solution was added to bring the hexane layer into the neck of the flask. The hexane layer was transferred to a screw top glass test tube (16 × 125 mm) with a borosilicate glass Pasteur pipette, followed by the addition of 4 mL of saturated sodium chloride solution, capped, and vortexed for 10 s and allowed to sit for 10 min. A portion of the hexane layer was transferred to a 1-mL borosilicate glass serum vial (#223682; Wheaton, Millville, NJ) containing a small amount of anhydrous sodium sulfate to absorb residual moisture. An 11-mm aluminum crimp top seal with a Teflon faced rubber septa (National Scientific Co., Lawrenceville, GA) was placed over the vial. Vials were stored at -15°C in darkness until GLC analysis. Methylation and GLC analysis were done in duplicate.

Fatty acid methyl ester (FAME) analysis. Test portions were analyzed by GLC with a DB-225, 50% cyanopropylphenyl 50% methylpolysiloxane capillary column [(30 m × 0.53 mm × 1 μm film thickness); J&W Scientific, Folsom, CA], installed in a Hewlett Packard 6890 GC System equipped with an automatic liquid sampler and a flame ionization detector (Hewlett Packard Co., Wilmington, DE). The temperature at the splitless inlet was 250°C with 300°C at the detector. The helium carrier gas had an initial column flow of 6.5 mL/min with a decrease to 5.5 mL/min at 17 min after test portion injection. A 1-μL injection of test portion or standard was analyzed under temperature programmed conditions with an initial oven temperature of 50°C for 1 min, increased at 12°C/min to 185°C and held for 3 min, increased at 4.5°C/min from 185°C to 210°C, and held for 6 min. Recoveries of fatty acids were determined by weighing individual free fatty acids (even carbon numbers 4 to 18 including 14:1, 16:1, 18:1, 18:2, and 18:3; Alltech Associates, Inc., Deerfield, IL) to produce a recovery standard with a fatty acid composition similar to milk fat. This quantitative standard mixture was methylated and analyzed using the same conditions as used for the test portions. Methylation of

the standards was repeated 3 $\times$, and 4 GLC injections were made for each methylation. The standard methyl esters were used to calculate the recovery factor for each fatty acid to convert from relative area percent to weight percent. Integration was performed with the Hewlett Packard Chemstation (Rev. A04.02) standard integrator software.

Triglyceride analysis. The molecular weight distribution of triglycerides was determined (Barbano and Sherbon, 1980). A 7-mL portion of the chloroform:lipid mixture was placed into a 25-mL 14/20 standard taper pear-shaped flask warmed with water. A stream of dry nitrogen was used to evaporate the chloroform. The residual lipid was diluted with hexane to a concentration of 50 g of fat/L. A portion was transferred to a 1-mL borosilicate glass serum vial (#223682; Wheaton, Millville, NJ). An 11-mm aluminum crimp top seal with a Teflon-faced rubber septa (National Scientific Co.) was placed over the vial. Vials were stored at -15°C in darkness until GLC analysis.

Test portions were analyzed by GLC with a DB-1, 100% dimethylpolysiloxane capillary column [(15 m $\times$ 0.32 mm $\times$ 0.1 μm film thickness), J&W Scientific], installed in a Hewlett Packard 6890 GC System with an automatic liquid sampler and a flame ionization detector. The temperature at the split inlet was 350 and 360°C at the detector. An injection volume of 1 μL was used with a split ratio of 20:1. The column had a constant flow of helium at 3.5 ml per minute. The initial oven temperature was set at 210°C . Upon injection, the oven increased temperature at a rate of 14°C per minute to a final temperature of 350°C and held at that temperature for 5 min. Test portions were analyzed in triplicate. The triglyceride recoveries (analyzed in triplicate) and identification of unsaturated and saturated triglycerides (by retention times) were determined using standards (trisaturates with carbon number 30, 36, 42, 48, 52, triunsaturates of 42 and 48; NuChek-Prep Inc. Elysian, MN). Integration was performed with the Hewlett Packard Chemstation (Rev. A04.02) standard integrator software.

The retention times of standards, tripalmitolein and tripalmitin are shown in Figure 1. Tripalmitolein eluted sooner than tripalmitin on the nonpolar column. The triglyceride with 48 fatty acid carbons, shown in Figure 2, was composed of 2 distinctly different groups of peaks (1 and 2 vs. 3). The group of larger peaks was separated into 2 peaks (1 and 2), which were not completely resolved. The 2 peaks (1 and 2) for triglyceride 48 (and other even number triglycerides) correspond to 2 groups of triglycerides with 48 carbons that differ in the degree of unsaturation, with peak 1 being more unsaturated than peak 2. A group of smaller peaks is circled and labeled 3 in Figure 2 and represents triglycerides with

Figure 1. Chromatogram of tripalmitolein (1) and tripalmitin (2) with peak retention time (min).

fatty acid chain lengths that produce an odd carbon number. The distinction between large group and small group of peaks is done for simplicity in analysis and discussion.

Thermal properties. A portion of the chloroform:lipid mixture was placed into a pear-shaped flask warmed with water. A stream of dry nitrogen was used to evaporate the chloroform. The stoppered flasks with the lipids were placed into a water bath set at 40°C during the weighing process to keep the lipid fully melted during the transfer to the sample pans. The lipids were weighed (about 5 mg) and sealed in small aluminum differential scanning calorimeter (DSC) pans (kit number 219-0062; Perkin-Elmer, Wellesley, MA). The test portions were analyzed with a DSC (2920 DSC; TA Instruments Inc., New Castle, DE). Samples were heated from 19°C initial temperature to 45°C at $5^{\circ}\text{C}/\text{min}$ and held at that temperature for 10 min to erase the test portion's thermal history. The test portion was then cooled to -64°C at $5^{\circ}\text{C}/\text{min}$ and held for 3 min. Finally, the test portion was heated to 65°C at $5^{\circ}\text{C}/\text{min}$. Accuracy of the temperature calibration of the DSC

Figure 2. Chromatogram of triglycerides (designated by carbon number) of full-fat Cheddar cheeses. More polar (1) and less polar (2) triglycerides divide triglyceride 48. The peaks with 49 carbons are grouped within the circle (3).

was verified using mercury, melting point -38.87°C ; *p*-xylene, melting point 13 to 14°C ; tristearin, melting point 72°C . Baseline calibration was verified by running the above method with empty aluminum pans. Three test portions were analyzed for each sample. Thermograms were analyzed using Thermal Analyst software [2100 System, version 8.10B (2.3A); TA Instruments Inc.]. Thermograms were integrated over 3 temperature intervals $< 20^{\circ}\text{C}$, 20 to 30°C , and above 30°C .

Flavor Intensity Comparison Between Full-Fat and Reduced-Fat Cheddar Cheeses

A portion of 3 commercial full-fat Cheddar cheeses labeled mild, sharp, and extra sharp was used to produce reduced-fat Cheddar cheeses by the fat removal process, 30°C at $23,500 \times g$ for 5 min. A fat reduction of 50% was targeted. Following fat removal by centrifugation, the cheese residue was chopped in a food processor equipped with a Sabetier blade (KitchenAid, St. Joseph, MI) and combined with water to adjust the final moisture to about 48%. No additional salt was added. The chopped reduced-fat cheese was placed into cylindrical polypropylene cheese molds (#M3; New England Cheesemaking Supply Co., Ashfield, MA) lined with poly webbing cheesecloth and pressed into shape by hand. After pressing by hand, the 7-kg cheese rounds were vacuum packaged. The remaining full-fat Cheddar cheese of each age was shredded and pressed into a round form in the same manner as the reduced-fat cheese to produce similar texture for both the full- and

reduced-fat cheeses to allow for direct comparison of flavor intensity. Cheeses were held at 6°C . The evening before tasting, cheeses were sliced (about 5 cm^2), wrapped in plastic wrap, placed in plastic soufflé cups with lids, and held at 6°C until tasting the next morning. Cheeses were presented to the panelists at 8 to 10°C .

Twelve untrained panelists were presented with a computer interfaced (Compusense, 2001) flavor intensity line scale from 0 to 10. Three full-fat Cheddar cheeses were provided to the panelists as flavor intensity references. Each reference cheese was shredded using a 2-mm shredding blade (model KFP6000B; KitchenAid), pressed, and portioned in the same manner as the full-fat cheeses described previously. Panelists were presented with the 3 reference cheeses and their respective scores, 1 = low intensity, 5 = moderate intensity, and 9 = high intensity, then asked to taste the reference cheeses before any tasting any of the unknown cheeses. The reference cheeses were chosen by the investigators because they had typical Cheddar flavor without apparent defects or off-flavors. Unknown cheeses were presented to the panelists in blind coded pairs. Each pair of unknown cheeses consisted of a reduced-fat and the respective full-fat Cheddar cheese it was made from. The tasting order of cheese pairs and the tasting order of reduced fat versus full fat in each pair were randomized. Panelists were given (on 4 different days) the reference cheeses, the 3 full-fat, the 3 reduced-fat cheeses, and asked to score these cheeses for overall flavor intensity relative to the references.

Table 1. Analysis of variance model for flavor intensity data with random and fixed effects.

Factors ¹	df	Error terms ²	df ³
FL (Fixed)	1	MS(DT × FL) + MS(P × FL) – MS(DT × P × FL) – (13 × 10 ⁻¹⁵ × MSE)	6.5
C (Fixed)	2	MS(P × C)	22
P (Random)	11	MS(DT × P) + MS(P × C) + MS(P × FL) – MS(DT × P × FL) – MSE	17.1
DT (Random)	3	MS(DT × P) + MS(DT × FL) – MS(DT × P × FL) – (4 × 10 ⁻¹⁵ × MSE)	4.4
DT × P (Random)	33	MS(DT × P × FL)	33
DT × FL (Random)	3	MS(DT × P × FL)	33
P × FL (Random)	1	MS(DT × P × FL)	33
P × C (Random)	22	MSE	166
C × FL (Fixed)	2	MSE	166
DT × P × FL (Random)	33	MSE	166

¹FL = fat level, C = cheese, P = panelist, and DT = day of tasting.

²MS = mean square, MSE = mean square of the error.

³The error degrees of freedom used to test the hypotheses for the mixed model were calculated using SAS (software version 8.02; SAS Institute Inc., Cary, NC).

Statistical Methods

Optimizing temperature, GF, and DAF for fat removal. A 3³ factorial design was used to determine the impact of 3 processing parameters temperature, GF, and DAF on the amount of fat removed from aged Cheddar cheese. Three temperature, three relative GF, and three durations were analyzed as categorical variables. Probability for the main effects, 2-way, and 3-way interactions were computed using the general linear models procedure of Statistical Analysis System (software version 8.02; SAS Institute Inc., Cary, NC) with fixed effects. The parameter estimates for the linear regression were determined using the regression procedure of SAS (software version 8.02; SAS Institute Inc., Cary, NC).

FAME, triglycerides, and thermal properties. A 2-way ANOVA procedure was used with cheese (3 different cheeses) and fat (reduced, full fat, and fat removed) as main effects. Each FAME and triglyceride carbon number group was analyzed separately. The general linear models procedure of SAS (software version 8.02; SAS Institute Inc.) was used to determine the variation and least significant difference of the means, if the model *F*-test was significant ($P < 0.05$).

Flavor intensity comparison between full-fat and reduced-fat Cheddar cheeses. Twelve panelists tasted 3 full-fat and 3 reduced-fat Cheddar cheeses made by fat removal from the 3 full-fat cheeses. Each panelist tasted each cheese on 4 different days. The factors and degrees of freedom for the statistical model are described in Table 1. Statistical analysis was performed with the general linear models procedure of SAS (software version 8.02; SAS Institute Inc.) with mixed effects.

RESULTS AND DISCUSSION

Optimization of Fat Removal Process

Fat removal was significantly influenced by temperature, GF, and the DAF ($P < 0.05$), shown in Table 2. Temperature had the greatest effect on fat removal from Cheddar cheese compared with GF and DAF (Table 2), as shown in Figures 3 and 4. Increasing the temperature by 5°C removed more fat for a given GF than extending the DAF 15 min (Figure 3). Similar results were obtained for the relationship between GF and the fat removed (Figure 4). A 5°C rise in temperature removes more fat at a given DAF than an 11-fold increase in DAF. The results shown in Figures 3 and 4 were expected since milk fat melts over a wide temperature range. The targeted fat removal, i.e., 50%, was achieved using fat removal conditions of 30°C at 23,500 × *g* for 5 min. The removed fat was a clear yellow liquid that was practically free of water and had very little flavor or aroma.

A wider range of temperatures—20, 22, 24, 28, 30, and 32°C—was used to better quantify the effect of temperature on the percent fat removed from Cheddar cheese. The percentage of fat removed had a positive linear relationship with temperature. The equation accompanying Figure 5 identifies the temperature required to produce reduced-fat cheeses with varying fat contents under the conditions of 23,500 × *g* for 5 min. The need for high GF and long DAF to achieve equivalent fat removal decreased with increasing temperature (Figure 4). When temperatures above 32°C (33 to 41°C, data not shown) were used, some water was expressed in addition to the liquid fat. Higher GF and longer DAF will increase water removal. If higher temperatures are used then lower GF and shorter DAF can be used. The removal of water from Cheddar cheese during fat re-

Table 2. Sum of squares (SS) and probability (P) for fat optimization of the fat removal process analysis of variance.

Source	df	SS	P
T ²	2	1.524	<0.0001
GF ³	2	0.130	<0.0001
DAF ⁴	2	0.035	<0.0001
T × GF	4	0.008	<0.0001
GF × DAF	4	0.004	0.0003
T × DAF	4	0.002	0.0076
T × GF × DAF	8	0.004	0.0016
Error	27	0.003	
Total	53	1.710	
R-square		0.998	
MSE ¹		0.0001	

¹Mean square of the error for the model.²T = temperature.³GF = gravitational force.⁴DAF = duration of applied force.

moval is not desirable because flavor will be lost with the water fraction (McGugan et al., 1979).

In its final form, the fat removal process started with 100 kg of aged Cheddar cheese. As an example, there would be 33.3 kg of fat, 37.1 kg of moisture, 1.8 kg of salt, 24.2 kg of protein, and 3.6 kg of other solids in the starting full-fat cheese. Some of the fat is removed from the cheese to produce 19.3 kg of liquid fat and 80.7 kg of reduced-fat cheese. To enhance reformation of the cheese into a block, 3.1 kg of water was added to the 80.7 kg of reduced fat cheese to produce 83.8 kg of 50% reduced fat cheese that contains 16.7% fat, 48% moisture, 2.1% salt, 28.9% protein, and 4.3% other solids. At the stage of water addition, other ingredients could be added. The amount of water added can be adjusted to obtain very uniform cheese composition and yield.

Figure 3. Effects of the DAP and temperature on fat removed (%), n = 2, from full-fat Cheddar cheese using a force (g max) of 23,500 × g, 20°C (▲), 25°C (■), 30°C (●).

Impact of the Fat Removal Process on Cheese Composition and Fat Characteristics

Cheese composition. The compositions of 3 full-fat and 3 reduced-fat Cheddar cheeses are listed in Table 3. The reduced-fat cheeses were produced by removing fat from the 3 full-fat cheeses. Each reduced-fat cheese exceeded 50% fat reduction. Fat reduction was a function of fat removal and the increase in moisture due to the added water. An observed trend with the cheeses in the study was that all other components increased, on a relative percentage basis, when fat was removed from the cheese. The amount of water added was less than the amount of fat removed. The fat removal process did not greatly affect the cheese pH.

Fatty acid composition. The fat removal process does affect the fatty acid composition of Cheddar cheese (Table 4). Generally, the reduced-fat Cheddar made us-

Figure 4. Effects of gravitational force and temperature on fat removed (%), n = 2, from full-fat Cheddar cheese. Centrifuged for 5 min, 20°C (▲), 25°C (■), 30°C (●).

Figure 5. Effect of temperature on fat removed (%), $n = 4$, from full-fat Cheddar cheese. Fat removed with a force (g max) of 23,500 $\times g$ for 5 min.

ing fat removal contains more saturated long-chain fatty acids. The fat removed during fat removal contains more short-chain and unsaturated long-chain fatty acids than the full- and reduced-fat cheeses. This result was not surprising because short-chain and unsaturated fatty acids have a lower melting point and would be removed in the liquid form before the saturated long-chain fatty acids. Hence, the short-chain and unsaturated fatty acids are removed when the temperature of full-fat cheese is increased and the long-chain saturated fatty acids remain in the cheese. Even though there was a statistically significant difference in the proportion of unsaturated to saturated fatty acids between the full-fat and reduced-fat lipid portions, the nutritional impli-

cations of this difference was not great. The cheeses shown in Table 3 have an average fat reduction of 52% corresponding to a decrease in fat per serving from 9.46 to 4.53 g (average across cheeses A, B, and C), while changing the amount of saturated fat per serving from 6.30 g to 3.10 g (average across cheeses A, B, and C) and unsaturated fat from 3.16 g to 1.43 g (average across cheeses A, B, and C) per serving. The proportion of saturated fat to unsaturated fat in the full-fat cheese was 1.99 to 1.00 (average across cheeses A, B, and C) and 2.17 to 1.00 (average across cheeses A, B, and C) in the reduced fat cheese made by fat removal. Clearly, the nutritional benefits of lower total, saturated, and unsaturated fat per serving are greater than the small increase in the proportion of saturated fat to unsaturated fat.

Triglyceride molecular weight distribution. The fat in cheese exists mostly in the triglyceride form. Fat removal affects the triglyceride molecular weight distribution (Tables 5 and 6) of cheese fat. For simplicity, the triglyceride chromatogram was divided into 2 groups, even- and odd-numbered peaks (Myher et al., 1988). Even carbon number triglycerides composed about 88 to 89% of the triglyceride molecular weight distribution. Most even-numbered triglycerides, in Figure 2, had partial resolution of more unsaturated and more saturated triglycerides of the same carbon number designated 1 and 2, respectively. Fat removal increased the amount of even-numbered triglycerides with carbon numbers from 46 to 52 in reduced-fat Cheddar cheese (Table 5). The fat removed from full-fat Cheddar cheese (30°C, 23,500 $\times g$ for 5 min) contained more even-numbered triglycerides with carbon numbers 28 to 42. A

Table 3. Composition of the Cheddar cheeses used for fatty acid methyl ester, triglyceride, and thermal analyses. Three full-fat (FF) Cheddar cheeses (A, B, and C) with their respective reduced-fat version (RF) made by fat removal.

Cheese	Fat reduced	Fat ¹	Moisture	Salt	S/M ²	Protein ³	pH 4.6 ⁴	12% TCA ⁵	TA ⁶	pH
%										
Cheese A										
FF	0	32.8	38.35	1.43	3.73	23.70	22.79	13.38	1.23	5.04
RF	51	16.0	49.11	2.20	4.48	27.81	23.91	14.67	1.35	5.07
Cheese B										
FF	0	34.3	35.89	1.57	4.37	24.23	24.43	14.53	1.37	5.00
RF	52	16.5	47.66	1.98	4.15	28.24	26.24	15.05	1.58	4.99
Cheese C										
FF	0	34.3	35.12	1.44	4.10	24.77	28.95	18.41	1.36	5.14
RF	53	16.0	48.32	1.63	3.37	28.53	30.07	20.08	1.44	5.13

¹Fat on a wet basis.

²S/M = (salt/moisture) $\times$ 100.

³Total nitrogen $\times$ 6.38.

⁴pH 4.6 soluble nitrogen expressed as a percentage of total nitrogen.

⁵12% TCA soluble nitrogen expressed as a percentage of total nitrogen.

⁶Titrateable acidity.

Table 4. Mean (n = 3) weight percentages of fatty acid methyl esters in the lipid portion of full-fat Cheddar cheese, reduced-fat Cheddar cheese produced by fat removal, and the removed fat.

Fatty acid ¹	Full-fat cheese	Reduced-fat cheese	Removed fat	LSD
	Weight %			
4:0	3.49 ^a	3.18 ^b	3.56 ^a	0.079
6:0	2.20 ^b	2.03 ^c	2.29 ^a	0.042
8:0	1.25 ^b	1.16 ^c	1.30 ^a	0.017
10:0	2.74 ^b	2.57 ^c	2.82 ^a	0.031
12:0	3.13 ^b	3.02 ^c	3.18 ^a	0.022
14:0	10.91 ^b	11.03 ^a	10.90 ^b	0.087
14:1	0.92 ^b	0.88 ^c	0.98 ^a	0.027
16:0	29.51 ^b	30.98 ^a	29.13 ^b	0.483
16:1	1.45 ^b	1.39 ^c	1.54 ^a	0.029
18:0	13.38 ^b	14.44 ^a	12.43 ^c	0.263
18:1	27.74 ^b	26.27 ^c	28.50 ^a	0.367
18:2	2.85 ^a	2.70 ^b	2.92 ^a	0.093
18:3	0.48	0.37	0.45	NS
Total	100	100	100	

^{a,b,c}Means within a row without a common letter differ ($P < 0.05$).

¹Carbon number (not including esterified methyl group):number of double bonds.

similar trend was observed for the odd carbon number triglycerides (Table 6).

Thermal properties of fat. Typical thermograms for the fat portion of full-fat and reduced-fat Cheddar cheeses are shown in Figures 6 and 7. The fat portion of reduced-fat cheese produced using fat removal appears to have more higher melting fat than does the full-fat cheese. The fat from full-fat Cheddar cheese melted from about -39°C to about 38°C . In contrast, the range of melting for the fat from the reduced-fat cheese was about -34°C to about 40°C . The removed fat melted from about -41°C to about 33°C . The re-

moved fat was missing the higher melting portion that was observed in the full- and reduced-fat cheeses, shown in Figure 8. The amount of liquid fat at 30°C increased in the following order; reduced-fat cheese, full-fat cheese, removed fat (Table 7). The fat removed at 30°C was almost 100% liquid, as described in Table 7 and shown in Figure 8. Thermal analysis of the fat after fat removal revealed that the functional characteristics of the fat in the reduced-fat cheese and the fat that was removed were different than the fat found in full-fat Cheddar cheese (Table 6 and Figures 6, 7, and 8). The higher melting characteristics did not make a

Table 5. Mean (n = 3) weight percentage of the even carbon number triglyceride groups in the lipid portion of full-fat Cheddar, reduced-fat Cheddar produced by fat removal, and the removed fat.

Triglyceride ¹	Full-fat cheese	Reduced-fat cheese	Removed fat	LSD
	Weight % ²			
28	0.72 ^a	0.66 ^b	0.74 ^a	0.030
30	1.28 ^a	1.17 ^c	1.32 ^a	0.030
32	2.49 ^b	2.33 ^c	2.56 ^a	0.026
34	5.27 ^b	4.97 ^c	5.49 ^a	0.098
36	10.13 ^b	9.59 ^c	10.59 ^a	0.231
38	13.25 ^b	12.48 ^c	13.76 ^a	0.212
40	10.99 ^b	10.23 ^c	11.34 ^a	0.300
42	6.76 ^b	6.46 ^c	6.95 ^a	0.112
44	5.88 ^a	5.92 ^a	5.91 ^a	0.145
46	6.51 ^b	7.01 ^a	6.27 ^c	0.172
48	8.15 ^b	9.12 ^a	7.67 ^c	0.300
50	10.99 ^b	12.14 ^a	10.35 ^c	0.384
52	11.28 ^b	11.78 ^a	10.89 ^c	0.317
54	6.30 ^a	6.13 ^a	6.19 ^a	0.464
Total	100	100	100	

^{a,b,c} Means within a row without a common letter differ ($P < 0.05$).

¹Number of carbons not including glycerol.

²Does not include odd carbon number triglycerides.

Table 6. Mean ($n = 3$) weight percentage of the odd carbon number triglyceride groups in the lipid portion of full-fat Cheddar, reduced-fat Cheddar produced by fat removal, and the removed fat.

Triglyceride ¹	Full-fat cheese	Reduced-fat cheese	Removed fat	LSD
	Weight % ²			
29	0.53 ^a	0.45 ^b	0.57 ^a	0.062
31	0.99 ^a	0.90 ^a	1.05 ^a	0.083
33	2.63 ^b	2.45 ^c	2.78 ^a	0.115
35	8.50 ^b	8.05 ^c	9.03 ^a	0.288
37	11.94 ^b	11.14 ^c	12.46 ^a	0.245
39	8.95 ^a	8.20 ^b	9.37 ^a	0.418
41	5.81 ^b	5.23 ^c	5.98 ^a	0.150
43	5.75 ^a	5.41 ^b	5.91 ^a	0.165
45	6.91 ^a	7.00 ^a	6.95 ^a	0.236
47	9.62 ^b	10.34 ^a	9.25 ^c	0.303
49	14.00 ^b	15.25 ^a	13.44 ^c	0.319
51	15.55 ^b	16.55 ^a	14.78 ^c	0.625
53	8.82 ^{ab}	9.03 ^a	8.43 ^b	0.597
55	ND ³	ND	ND	
Total	100	100	100	

^{a,b,c}Means within a row without a common letter differ ($P < 0.05$).

¹Number of carbons not including glycerol.

²Does not include even carbon number triglycerides.

³ND = not detectable.

noticeable impact on texture of the reduced-fat Cheddar because the fat content was reduced and the moisture content was increased. However, the removed fat was softer than whole milk fat.

Impact of the Fat Removal Process on Sensory Characteristics

Texture. The texture results reported by Bryant et al. (1995) are typical of the reduced-fat cheeses made by removing fat from milk prior to cheese making. The hard texture associated with reduced-fat Cheddar cheeses can be explained by a decrease in filler volume. Increasing the filler volume by increasing the moisture

content of the cheese does not compensate for the large decrease in the fat portion of the filler volume. Increasing the filler volume of a composite is not the only way to change the texture in a filled-gel composite model. Visser (1991) noted that disrupting the gel structure changes the texture properties of the composite. The shredding and chopping steps of the fat removal process, described in our research, disrupts the integrity of the casein gel structure. This softens the texture of the reduced-fat Cheddar cheese in spite of the decrease in total filler volume. The reduced-fat Cheddar cheese made by the removal of fat from the cheese creates a softer product that breaks up and dissipates quickly in

Figure 6. Typical melting profile of fat from full-fat Cheddar cheese. **Figure 7.** Typical melting profile of fat from reduced-fat Cheddar cheese produced by the fat removal process. Fat removal conditions ($g \text{ max}$) 23, $500 \times g$ for 5 min at 30°C.

Figure 8. Typical melting profile of fat removed from full-fat Cheddar cheese by the fat removal process. Fat removal conditions (g max 23, $500 \times g$ for 5 min at 30°C).

the mouth. The texture was subjectively described by panelists as creamier and softer than the original full-fat cheese.

Flavor intensity. Three aged full-fat Cheddar cheeses, identified as D, E, and F, were converted to reduced-fat Cheddar cheeses using fat removal; their compositions are shown in Table 8. The percent fat reduction achieved in the cheeses produced for the flavor intensity evaluation phase of this research was slightly higher (mean = 55%) than the fat reduction achieved in the production of the reduced-fat cheeses used for the fatty acid, triglyceride, and thermal analyses (mean = 52%).

The mean flavor intensity scores for the unknown cheeses are shown in Table 8. The compositions and flavor intensity scores for the reference cheeses are also presented in Table 8. The moderate intensity reference cheese was also used as the unknown full-fat cheese E. This was done to evaluate the use of the reference cheeses by the panelists. The panelists were given the moderate intensity reference along with its respective flavor intensity score of 5.0. The mean score for the full-fat unknown cheese E was 5.3. The small difference between the scores for the full-fat cheese E and the

moderate reference indicated that the panelists correctly used the references to evaluate the flavor intensity of the unknown cheeses.

The flavor intensities of the unknown cheeses (D, E, and F) were significantly different from each other ($P < 0.05$) as shown in Table 9. Differences among cheeses were expected because cheeses were commercially labeled mild (D), sharp (E), and extra sharp (F). The main effect of fat level (Table 9), either full-fat or reduced-fat, was not significant ($P > 0.05$). However, the interaction, cheese by fat level, was significant ($P < 0.05$). The difference between the flavor intensity of the full- and reduced-fat cheeses within each cheese (D, E, and F) increased with increasing flavor intensity of the full-fat cheese. The difference between the mild full- and reduced-fat cheeses was 0.3 compared with 1.6 for the extra sharp cheeses (Table 8). The panelist $\times$ fat level interaction was also significant ($P < 0.05$). Six panelists scored the full-fat cheeses higher in flavor intensity, and six scored the reduced-fat cheeses higher in flavor intensity (data not shown). Panelists scoring the full-fat cheeses higher recorded smaller differences between full- and reduced-fat cheeses (data not shown). In contrast, those who scored the reduced-fat cheeses higher in flavor intensity recorded a greater difference between the full- and reduced-fat cheeses (data not shown).

In general, based on the limited data presented in this paper, it appears that flavor intensity may be increased more for reduced-fat cheeses made from higher flavor intensity full-fat cheeses. However, if the full-fat cheese has an undesirable flavor, then we expect that the undesirable flavor will be increased in intensity also. The rate of flavor release by the cheese when placed in the mouth seemed to be faster for the reduced-fat cheese, compared with the original full-fat cheese, particularly for more intensely flavored cheese. This may be due to the larger amount of water (with the flavor compounds it contains) and salt in a unit weight of cheese put into the mouth, which may deliver more water soluble flavor compounds per unit weight of cheese.

A subjective evaluation, by the researchers, of the fat removed during fat removal from Cheddar cheese characterized the fat as flavorless. The aroma of the

Table 7. Mean ($n = 3$) percentage of the fat that is liquid at 20, 30, and 40°C in full-fat Cheddar cheese, reduced-fat cheese produced by fat removal, and the removed fat.

Temperature ($^\circ\text{C}$)	Full-fat cheese	Reduced-fat cheese	Removed fat	LSD
	% Fat in the liquid form			
20	73.7 ^b	60.7 ^c	84.5 ^a	4.02
30	92.8 ^b	82.1 ^c	99.6 ^a	2.68
40	100	100	100	

^{a,b,c}Means within a row without a common letter differ ($P < 0.05$).

Table 8. Composition and flavor intensity score of cheeses used in flavor intensity sensory analysis. Three full-fat (FF) Cheddar cheeses (C, D, and E) with their respective reduced-fat version (RF) made by fat removal and 3 reference full-fat Cheddar cheeses.

Cheese	Fat reduced	Fat ¹	Moisture	Salt	S/M ²	Protein ³	pH 4.6 ⁴	12% TCA ⁵	TA ⁵	pH	Flavor intensity ⁶
%											
Unknown											
Cheese D											
FF	0	33.3	37.05	1.76	4.75	24.19	24.70	13.04	1.33	5.14	3.9
RF	55	15.0	49.20	2.09	4.25	28.07	22.86	14.87	1.41	5.19	3.6
Cheese E											
FF	0	33.5	35.97	1.92	5.34	24.30	28.13	16.34	1.14	5.34	5.3
RF	56	14.8	46.94	2.39	5.09	30.10	28.38	16.40	1.37	5.34	4.8
Cheese F											
FF	0	33.3	37.23	1.78	4.78	23.87	26.84	15.81	1.36	5.09	5.5
RF	55	15.0	48.85	1.86	3.81	28.79	26.19	15.43	1.73	5.05	7.1
Reference											
Low intensity ⁷	0	33.5	37.22	1.77	4.76	23.12	14.57	7.54	0.97	5.15	1.0
Moderate intensity ⁷	0	33.5	35.97	1.92	5.34	24.30	28.13	16.34	1.14	5.34	5.0
High intensity ⁷	0	35.3	35.43	1.64	4.63	24.20	37.66	24.01	1.50	5.32	9.0

¹Fat on a wet basis.²S/M = (salt/moisture) × 100.³Total nitrogen × 6.38.⁴pH 4.6 soluble nitrogen expressed as a percentage of total nitrogen.⁵12% TCA soluble nitrogen expressed as a percentage of total nitrogen.⁶Titrateable acidity.⁷Mean flavor intensity (n = 12). Panelists used a flavor intensity line scale, 0 to 10, defined with low, moderate, and high flavor intensity references (1, 5, and 9, respectively). Moderate intensity reference cheese is the same cheese as full-fat cheese E.

removed fat was mild and buttery. The utilization of the removed fat is vital for the economic success of an industrial process. The sensory panelists found the 50% reduced-fat Cheddar cheeses made by removing fat from aged Cheddar cheese were at least as intense in flavor as the original aged full-fat Cheddar cheeses.

CONCLUSIONS

There is a need in the dairy industry for a reduced-fat Cheddar cheese with better flavor than the current

reduced-fat cheeses. Fat removal from full-fat aged Cheddar cheese resulted in a reduced-fat Cheddar cheese with flavor at least as intense as the original full-fat cheese. Fat removal from Cheddar cheese was predominately influenced by the temperature of the cheese. The GF and DAF influenced fat removal but to a lesser extent than temperature. The fat removal process changes the fatty acid composition and the triglyceride molecular weight distribution of the fat portion of the cheese. The important difference between the full- and reduced-fat cheeses with respect to the

Table 9. Sum of squares (SS) and probability (*P*) for flavor intensity analysis of variance, comparing 3 full-fat Cheddar cheeses with their respective 50% reduced-fat cheeses produced using fat removal.

Source	df	SS	<i>P</i>
Cheese	2	309.25	<0.0001
Panelist	11	259.30	0.0266
Day of tasting	3	12.59	0.4568
Fat level	1	5.95	0.3642
Day of tasting × panelist	33	106.46	0.1663
Panelist × cheese	22	95.83	0.0184
Cheese × fat level	2	66.15	<0.0001
Panelist × fat level	11	60.06	0.0268
Day of tasting × fat level	3	9.25	0.2770
Day of tasting × panelist × fat level	33	75.72	0.5373
Error	166	397.17	
Total	287	1397.74	
R-square		0.72	
MSE ¹		2.39	

¹Mean square of error for the model.

nutritional characteristics was the 50% reduction in grams of fat per serving of cheese. The small increase in the proportion of saturated to unsaturated fat was not a nutritional concern. The fat removal process alters the thermal characteristics of the fat in the reduced-fat cheese and the removed fat with respect to the fat found in the original full-fat Cheddar cheese.

The flavor intensity of full-fat Cheddar cheese was preserved when converted to reduced-fat Cheddar cheese by the fat removal process. The fat removed from the Cheddar cheeses in this study had little if any flavor but did possess a mild aroma. In this study, reduced-fat cheeses with 55% less fat were produced using the fat removal process. Reduced-fat cheeses had a flavor that was at least as intense as the original full-fat cheeses.

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