The Effect of Milk Fat on Cheddar Cheese Yield and Its Prediction, Using Modifications of the Van Slyke Cheese Yield Formula

M. A. FENELON* and T. P. GUINEE*,1
*Dairy Products Research Centre, Teagasc, Moorepark, Fermoy, County Cork, Republic of Ireland

ABSTRACT

This study investigated the effect of milk fat content, in the range 0.54 to 3.33% (wt/wt), on rennet coagulation properties and the composition, actual yield, and predicted yield, as determined by the Van Slyke formula, of low-fat, half-fat, reduced-fat, and full-fat Cheddar cheeses. The yields predicted using the original Van Slyke formula were significantly lower than the corresponding actual yields for the low-fat, half-fat, and reduced-fat Cheddar cheeses. A more accurate prediction of cheese yield was obtained when the Van Slyke formula was modified to account for denaturation of whey protein on pasteurization and for the differences in fat recovery and content of nonfat, nonprotein cheese solids among cheeses of different fat contents. Increasing milk fat content resulted in cheese with significantly higher contents of fat, moisture in the nonfat substance, and salt-in-moisture and lower contents of moisture, protein, and ash. Both actual and dry matter cheese yields increased with milk fat content in the range 0.54 to 2.00% (wt/wt). However, further increase in milk fat content to 3.33% (wt/wt) resulted in an increase in the proportion of milk fat lost to the cheese whey.

(Key words: milk fat, cheese yield, Cheddar cheese)

Abbreviation key: FFC = full-fat Cheddar, G’ = elastic shear modulus, HFC = half-fat Cheddar, LFC = low-fat Cheddar, MNFS = moisture in the nonfat substance, RFC = reduced-fat Cheddar, SNFP = solids nonfat non-protein.

INTRODUCTION

Cheese yield may be defined as the weight of cheese obtained from a given weight of milk with defined contents of casein and fat. It is a major factor influencing the efficiency and profitability of cheese making (12). The increased global supply of cheese coupled with the general escalated cost of raw materials and manufacturing facilities has resulted in greater attention being focused on factors influencing cheese yield and means of improving cheese-making efficiency.

Cheese yield is influenced by many factors, including milk composition, milk pretreatments, coagulant type, curd firmness at cutting, cutting program, vat design, and curd handling systems (2, 4, 14, 30, 31, 32, 34). In many cheese yield studies, the separate effects of differences in contents of milk fat or protein on cheese yield are not easily interpreted because of the interfering effects of changes in stage of lactation, season (somatic cell count, casein to fat ratio, and milk pH) or diet, or both. However, the findings of studies that have segregated the effects of diet, stage of lactation, and protein genotype have shown that the influence of these parameters is at least partly due to their effect on the content of milk protein. Increasing the content of milk protein (in the range 3.0 to 4.5% wt/wt) while retaining a constant fat to protein ratio, results in linear increases in both actual and moisture-adjusted Cheddar cheese yields (17, 18). However, the increase in actual yield was higher than the corresponding increase in moisture-adjusted yield because of the inverse relationship between cheese moisture and milk protein content.

Because of the relatively large increase in the demand for reduced-fat cheeses (8) and the ongoing developments in lowering the fat content in cheese, a need exists to quantify the effect of reducing the fat content of milk on various aspects of cheese such as composition, yield, and recoveries. However, little information, apart from that of Gilles and Lawrence (13), has been reported on the direct effects of varying milk fat content on cheese yield. These authors found that the actual yield increased linearly with milk fat content in the range 0.07 to 4.0% (wt/wt).

The objectives of the current study were to investigate the effects of altering the content of milk fat from 0.54 to 3.33% (wt/wt) on 1) the composition and yield of the resultant Cheddar cheeses and wheys and 2) the application of a modification of the Van Slyke cheese yield formula for predicting Cheddar cheese yield.

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1Corresponding author: Tim Guinee, Dairy Products Research Centre, Teagasc, Moorepark, Fermoy, County Cork, Ireland.

MATERIALS AND METHODS

Standardization and Pasteurization of Milks

Raw milk was obtained from a local dairy company. Part of the milk was separated at 55°C, and the resultant skim milk was added to whole milk to give standardized milks with casein to fat ratios of 4.71, 1.68, 1.26, or 0.75. These milks were held overnight at 4°C. On the following day, the milks were pasteurized at 72°C × 15 s, cooled to 31°C, pumped separately to four identical cheese vats, and converted to Cheddar cheeses of different fat contents: full-fat Cheddar cheese (FFC), reduced-fat Cheddar (RFC), half-fat Cheddar (HFC), and low-fat Cheddar (LFC).

Rennet Coagulation Properties

A sample (100 ml) of renneted milk was taken from the cheese vat, 2 min post rennet addition and stirring, via an insulated glass container (previously tempered to 31°C) to the laboratory. A subsample (~13 g) was immediately placed in the cell (tempered to 31°C) of a controlled-strain rheometer (Bohlin VOR, Bohlin Reologi, Lund, Sweden), and the elastic shear modulus (G' (17)) was measured, at 31°C, with low amplitude strain oscillation, as described by Guinee et al. (17). The G’, which was used as an index of curd firmness, was measured 4 min from the time of rennet addition, and the values were recorded continuously at 30-s intervals over 1 h. This period was sufficient for all milk samples to attain a G’ value of 51 to 53 Pa (i.e., the firmness at which all gels in the cheese vat were cut).

Cheese Manufacture

Cheese making was performed in jacketed, stainless steel, 500-L, cylindrical vats, with variable speed cutting and stirring (CH-3076; APV Schweiz AG, Worb, Switzerland). Pasteurized milks were inoculated with Cheddar cheeses in the cheese vat were cut).

Sampling and Mass Balance

Pasteurized milks were weighed to the nearest 0.1 kg into 500-L cheese vats, each mounted on three load cells (type 500 kgf IP 68; Tdea Huntleigh Ltd., Cardiff, United Kingdom). Representative samples of pasteurized milks were taken immediately prior to addition of starter culture.

After cooking, the curd-whey mixture was pumped to jacketed finishing vats, where the curd was allowed to settle for ~5 min. A drum pump (model 16420; ITT Jabsco, Hodderson, United Kingdom) drew the drain whey through a 1-mm sieve (to exclude curd particles), and returned it to the empty cheese vat. The additional whey expressed from the cheese during cheddaring was also returned to the cheese vat. This whey, referred to as the bulk whey, was weighed and stirred (at 30 rpm/min) for 5 min, and a representative sample taken.

For three trials, the whey that was expressed on salting, mellowing, and overnight pressing was collected separately for the cheeses from each vat. Separate whey collection during pressing was achieved by placing the individually molded cheeses from each vat in polyethylene (80-μm gauge)-lined, block-bottom paper bags (before placing on the horizontal cheese press). The total white whey expressed on salting, mellowing, and pressing was placed in glass containers, weighed, and tempered to 50°C (to liquefy all fat), and a representative sample was obtained. All samples of milk and whey were preserved using 0.2 g of NaN₃/L, and their compositions were analyzed within 72 h.

The total curd from each vat was weighed at milling. The salted curd was weighed, placed in hoops, pressed overnight, and reweighed to get the final weight of cheese. In 3 of 24 vats, curd in excess of that which could be placed in hoops remained; thus for these 3 vats the final weight of curd was calculated as follows:

\[ W = W_1 + [W_3 \times (W_1/W_2)] \]
TABLE 1. Mass balance for a full fat Cheddar cheese.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>(kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasteurized milk</td>
<td>454.8</td>
</tr>
<tr>
<td>Starter</td>
<td>6.37</td>
</tr>
<tr>
<td>Rennet solution</td>
<td>1.00</td>
</tr>
<tr>
<td>Salt</td>
<td>1.44</td>
</tr>
<tr>
<td>Fat in milk + starter</td>
<td>16.40</td>
</tr>
<tr>
<td>Protein in milk + starter</td>
<td>16.46</td>
</tr>
<tr>
<td>Total weight</td>
<td>463.61</td>
</tr>
<tr>
<td>Fat + protein</td>
<td>32.86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese¹</td>
<td>46.98</td>
</tr>
<tr>
<td>Bulk whey</td>
<td>409.86</td>
</tr>
<tr>
<td>White whey</td>
<td>5.97</td>
</tr>
<tr>
<td>Fat in cheese</td>
<td>14.55</td>
</tr>
<tr>
<td>Fat in bulk whey</td>
<td>1.71</td>
</tr>
<tr>
<td>Fat in white whey</td>
<td>0.14</td>
</tr>
<tr>
<td>Protein in cheese</td>
<td>12.46</td>
</tr>
<tr>
<td>Protein in bulk whey</td>
<td>3.92</td>
</tr>
<tr>
<td>Protein in white whey</td>
<td>0.06</td>
</tr>
<tr>
<td>Total weight</td>
<td>462.81</td>
</tr>
<tr>
<td>Fat + protein</td>
<td>32.84</td>
</tr>
</tbody>
</table>

¹Salt included.

where W = final weight of curd, W1 = weight of pressed curd, W2 = weight of curd placed in hoops before pressing, and W3 = weight of excess unmolded (unpressed) curd. A typical example of mass balance for the FFC from trial 1 is presented in Table 1.

Compositional Analysis of Milks and Wheys

For clarity of presentation, cheese milk, which is pasteurized milk with added starter culture, is referred to simply as milk in the remainder of the text; all other milks, where mentioned, are supplied with the appropriate description (e.g., raw, unpasteurized, or pasteurized). Samples of raw, standardized, and pasteurized milks were analyzed for fat with the Röse-Gottlieb method (27) and for total nitrogen (26), casein (CN) (19), and nonprotein nitrogen (NPN) (26). The protein content in the milk was calculated using the following formula:

\[
Pm = (Ppm \times 0.986) + (Psi \times 0.014)
\]

where Pm, Ppm, and Psi correspond to protein contents of the milk, pasteurized milk, and starter inoculum, respectively; and coefficients 0.986 and 0.014 correspond to the weight fraction of pasteurized milk and starter inoculum in the milk. Similarly, the fat content of the milk was calculated using the above formula, in which protein values were replaced with the corresponding fat values. The casein content of the milk (Cm) was calculated using the following formula:

\[
Cm = [Ppm \times (CN\%TPum/100) \times 0.986] + [Psi \times (CN\%TPsi/100) \times 0.014]
\]

Where, CN\%TPum and CN\%TPsi are casein, as a percentage of total protein, in the unpasteurized milk and starter inoculum, respectively. Casein as calculated for the starter inoculum using this formula consisted of true casein and denatured whey protein complexed with the casein. However, it was not possible to calculate true casein for the starter because the casein content of the milk used to prepare the skim milk powder, from which the starter inoculum was prepared, was not available. Hence, for the purpose of this study we assumed that the casein content of the starter inoculum as calculated in the above formula was true casein. Moreover, as the starter inoculum formed only a small weight fraction of the total cheese milk, it was assumed that the denatured whey protein derived therefrom had little impact on the true casein content of the milk.

Undenatured whey protein (WP), as a percentage of the total protein in the milk, was calculated using the formula:

\[
WPm = (WPpm \times 0.986) + (WPsi \times 0.014)
\]

The undenatured whey protein in the unpasteurized and pasteurized milks were calculated using the following formula:

\[
WP = 100 - CN\%TP - \% NPN
\]

where CN\%TP is casein as a percentage of total protein, and \% NPN is nonprotein N as a percentage of total N. The percentage whey protein denaturation (%WPD) on pasteurization was calculated using the formula:

\[
%WPD = [(WPum - WPpm) \times 100] / WPum
\]

where um and pm refer to the unpasteurized milk and pasteurized milks, respectively.

Bulk wheys and white wheys were analyzed for fat by the Röse-Gottlieb method (22), and fines were analyzed by a modification of the method of Van den Berg et al. (37). In this modification the sediment was poured onto Whatman GF/F filter paper that had been predried and preweighed. The filter paper was then dried and reweighed. The filtered whey was analyzed for protein (26).

Analysis of Cheese

Grated cheese samples were analyzed at 14 d in triplicate for protein with the Kjeldahl method (26), fat with the Röse-Gottlieb method (21), salt (23), and moisture...
Cheese Yield Expression

Cheese yield was expressed as actual yield (YA, kg/100 kg) and dry matter cheese yield (YDM, kg/100 kg). The YDM was determined using the following formula:

\[ \text{YDM} = \frac{\text{YA} \times (100 - \text{MD})}{100} \]

where YA = yield, MD = moisture content, and 100 = constant. The use of this expression allowed the effect of milk fat content on cheese solids recovery to be expressed without the interfering effect of differences in moisture content as with actual yield.

The predicted cheese yield (YP) was determined using the original Van Slyke equation (39)

\[ \text{YP} = \frac{[F \times 0.93 + \text{CN} - 0.1] \times 1.09}{1 - \left(\frac{\text{Md}}{100}\right)} \]

where F = percentage fat in the milk; CN = percentage casein in the milk calculated using the CN%TP of the unpasteurized milk and CN%TP of the starter inoculum as discussed previously; 1.09 is a coefficient to account for nonfat nonprotein cheese solids (SNFP); and Md = reference moisture content, which in the current study was taken as the mean moisture content for each cheese fat category (i.e., 46.3, 42.9, 40.9, and 37.7% for the LFC, HFC, RFC, and FFC cheeses, respectively). Several modifications were made to Equation [1], resulting in a yield formula for predicting the yields of Cheddar cheeses of different fat contents. This formula, described by Equation [2], is discussed in the Results and Discussion section.

Statistical Analysis

A randomized, complete block design was used, which incorporated the four treatments: low-fat, half-fat, reduced-fat, and full-fat milks or cheeses. There were six replicate trials for each treatment. Analysis of variance was carried out using an SAS procedure (36) in which the effect of treatment and replicates were estimated. Duncan’s multiple-comparison test was used as a guide for pair comparisons of the treatment means.

The ANOVA was also used to compare the differences between actual yields and yields predicted by Van Slyke’s formula, as in Figure 6. In this case there were two treatments, actual yield and predicted yield, with six replicates for each treatment. Where the slope (m) of a regression line is given in the text, the confidence limits (at 95%) are also specified. The confidence limits are \( m \pm t \times \text{SE}_m \), where \( \text{SE}_m \) (obtained from the Microsoft Excel function LINEST) is the standard error of estimate of \( m \), \( m \) is the slope of the regression line, and \( t \) is the 2-tailed \( t \)-value associated with \( P = 0.05 \) and \( n - 2 \) degrees of freedom.

RESULTS AND DISCUSSION

Milk Composition

The mean compositions of the raw milks used in the six replicate trials were fat, 3.7; protein, 3.32; and lactose, 4.4 (% wt/wt). These values were typical for Irish milks obtained in midlactation (33). The compositions of the milks from the six replicate trials are given in Table 2; also included are the casein contents of the unpasteurized and pasteurized milks. Increased milk fat content was paralleled by a small reduction in the protein content; the mean level in the full-fat milk (3.33% wt/wt) was significantly lower than that in either the low- (0.54% wt/wt) or reduced- (2.0% wt/wt) fat milk. The apparent casein content increased significantly on pasteurization, an effect that may be attributed to the complexing of denatured whey proteins with the \( \kappa \)-CN (11, 38, 41). Denatured whey proteins precipitate with the caseins on acidification of the milk to pH 4.6, as in the assay for determination of casein content (19). The degree of whey protein denaturation during pasteurization (72°C for 15 s) varied from 6.0 to 8.0% of total whey protein, being similar in magnitude (~5%) to that obtained by Lau et al. (29) for batch pasteurization (63°C × 30 min).

Rennet Coagulation Characteristics

Increasing the content of fat in the milk enhanced its rennet coagulability (Figure 1), as reflected by the reduction in gelation time (i.e., time at which \( G' \) begins to increase). Enhanced rennet coagulability was also shown by the increase in curd-firming rate (i.e., slope of the \( G'/\text{time} \) curve in the linear region) and curd firmness (i.e., \( G' \)) at most times following the onset of gelation. This trend concurred with previous findings (9, 16) and may be attributed to the increase in the contribution of the milk fat to the gel elasticity (16). The viscosities of milk fat and milk plasma at 30°C are 45.7 and 1.26 mPa·s, respectively (40). Hence, increasing the fat content of the renneting milk system has the effect of increasing its elastoviscosity and decreasing the viscoelasticity; thereby the elastic shear modulus \( G' \) increases. In the current study, the positive effect of the fat on rennet coagulation properties overrode the concomitant negative effect associated with the slight dilution of the protein content. The improvement in the curd-forming properties of the milk, as the fat content

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Table 2. The compositions of milks used for the manufacture of Cheddar cheeses of different fat contents.1

<table>
<thead>
<tr>
<th>Cheese type</th>
<th>Fat (%)</th>
<th>Protein (%)</th>
<th>CN2</th>
<th>CN3</th>
<th>CN4</th>
<th>% WPD</th>
<th>CN:Fat ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low fat</td>
<td>0.54a</td>
<td>3.36a</td>
<td>2.53a</td>
<td>2.59a</td>
<td>2.54a</td>
<td>6.03a</td>
<td>4.71a</td>
</tr>
<tr>
<td>Half fat</td>
<td>1.50b</td>
<td>3.33ab</td>
<td>2.51ab</td>
<td>2.55b</td>
<td>2.51ab</td>
<td>6.87a</td>
<td>1.68b</td>
</tr>
<tr>
<td>Reduced fat</td>
<td>2.00b</td>
<td>3.34a</td>
<td>2.52a</td>
<td>2.56ab</td>
<td>2.52a</td>
<td>7.97a</td>
<td>1.26c</td>
</tr>
<tr>
<td>Full fat</td>
<td>3.33a</td>
<td>3.28b</td>
<td>2.47b</td>
<td>2.51c</td>
<td>2.48b</td>
<td>6.82a</td>
<td>0.75d</td>
</tr>
<tr>
<td>SED</td>
<td>0.055</td>
<td>0.022</td>
<td>0.017</td>
<td>0.019</td>
<td>0.017</td>
<td>1.285</td>
<td>0.134</td>
</tr>
</tbody>
</table>

Values presented are the means of 6 replicates.

a,b,c,dValues within a column not sharing a common superscript differ \((P < 0.05)\).

1All compositional parameters apart from casein in raw and pasteurized milk refer to standardized, pasteurized milk adjusted for added starter culture.
2Casein in raw milk.
3Casein in pasteurized milk.
4Casein in milk [i.e., pasteurized milk with 1.4% (wt/wt) added starter culture].
5WPD = Whey protein denaturation caused by pasteurization.
6SED = standard error of difference; degrees of freedom = 15.

Increased, was reflected by a corresponding reduction in set-to-cut times during cheese manufacture, (e.g., typically from ~61 min for the LFC to 50 min for the FFC).

Apart from a notable increase in the volume fraction of the fat phase, increasing the content of milk fat had no notable effects on the microstructure of the rennet gels at cutting (results not shown). While fat in the milk contributed to the rheological characteristics of the gel as a whole (e.g., by increasing firmness), it may be considered a noninteractive filler within the gel (3), which does not influence the structure of the paracasein network.

Cheese Composition

Increase of the milk fat content had marked effects on cheese composition (Table 3). Consistent with the findings of Gilles and Lawrence (13), increase of the milk fat content (kg/100 kg) was paralleled by significant \((P < 0.05)\) linear reductions in cheese moisture (3.1 ± 0.38%/kg), protein (4.55 ± 0.57%/kg), and ash (0.39 ± 0.184%/kg). Significant increases were also found in the contents of moisture in nonfat substance (MNFS) (1.58 ± 0.52%/kg) and fat in dry matter (12.71 ± 1.35%/kg) (Figure 2). The SNFP, which consists of nonfat nonprotein cheese solids, showed a similar trend to cheese moisture, increasing (0.020 ± 0.005%/kg) as the content of milk fat (kg/100 kg) was reduced. The salt content, expressed as grams of salt/100 g of cheese, was not significantly affected by the content of milk fat; in contrast, the content of salt in the moisture phase increased linearly (0.3 ± 0.13%/kg) with milk fat content (regression lines not shown).

Whey Weight and Composition

The weights and compositions of the cheese wheys from the different milks are presented in Table 4. Although the weight of bulk whey decreased significantly \((P < 0.05)\) as milk fat content increased, the opposite trend was noted for white whey. The reduction in the weight of white whey as the milk fat increased may be attributed to the lower-fat cheeses having presumably lower contents of MNFS at pressing (and, hence, less moisture available for expulsion on subsequent press-
TABLE 3. Compositions of Cheddar cheeses made from milk standardized to different fat contents.

<table>
<thead>
<tr>
<th>Cheese type</th>
<th>Moisture (%) wt/wt</th>
<th>Fat (%)</th>
<th>FDM</th>
<th>MNFS</th>
<th>S/M</th>
<th>Protein</th>
<th>Ash</th>
<th>Ca (mg/100 g)</th>
<th>P (%)</th>
<th>SNFP (mg/100 g)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low fat</td>
<td>46.29 a</td>
<td>6.88d</td>
<td>12.81d</td>
<td>49.71c</td>
<td>4.00c</td>
<td>39.31a</td>
<td>5.02a</td>
<td>1094a</td>
<td>737a</td>
<td>0.16a</td>
<td>5.27a</td>
</tr>
<tr>
<td>Half fat</td>
<td>42.85 b</td>
<td>17.41c</td>
<td>30.46c</td>
<td>51.88b</td>
<td>4.41b</td>
<td>33.36b</td>
<td>4.56b</td>
<td>935b</td>
<td>679b</td>
<td>0.13b</td>
<td>5.22b</td>
</tr>
<tr>
<td>Reduced fat</td>
<td>40.92 c</td>
<td>22.06b</td>
<td>37.34b</td>
<td>52.50b</td>
<td>4.54ab</td>
<td>31.19c</td>
<td>4.46b</td>
<td>894b</td>
<td>639b</td>
<td>0.11c</td>
<td>5.28a</td>
</tr>
<tr>
<td>Full fat</td>
<td>37.74 d</td>
<td>30.77a</td>
<td>49.42a</td>
<td>54.51a</td>
<td>4.85a</td>
<td>26.07d</td>
<td>3.87c</td>
<td>742a</td>
<td>534a</td>
<td>0.10d</td>
<td>5.25a</td>
</tr>
</tbody>
</table>

SED = 0.345 0.312 0.522 0.458 0.159 0.355 0.09 17 11 0.005 0.029

Values presented are the means of 6 replicates.

1FDM = fat dry matter, MNFS = moisture in the nonfat substance, and S/M = salt in moisture.

2Solids nonfat nonprotein as a fraction of total fat and protein. The SNFP was calculated using the following relationship: [(100 − moisture) − (fat + protein)]/(fat + protein).

3Standard error of difference; degrees of freedom = 15.

ing) and more closely packed protein matrices, which impede whey expulsion.

The fat in the bulk and white wheys increased significantly with content of fat in the milk, at rates of 0.13 ± 0.03% and 0.71 ± 0.16% per percentage milk fat, respectively (regression lines not shown). Simultaneously, the weight of fat in the bulk whey, as a percentage of the total milk fat, decreased significantly on increasing the fat content in the milk from 0.54 to 2.0% (wt/wt) (Table 4). However, a further increase in milk fat to 3.33% (wt/wt) resulted in a higher percentage of fat being lost to the cheese whey. The latter trend may be tentatively attributed to a number of factors including the concomitant reduction in volume of the bulk whey, which acts as a vehicle for the transport of liquefied fat droplets from the curd to the whey. Moreover, it is envisaged that the increase in the volume fraction of the fat phase as the fat content in the milk increases results in a greater extent of clumping of milk fat globules during cheese manufacture (15). This phenomenon might be due to shrinkage of the casein matrix around the occluded fat globules and collision of fat globules on movement within the matrix. The probable consequence of this partial clumping is an increase in the effective size of the fat globules, an occurrence that impedes their movement through the paracasein matrix, to the whey. Furthermore, the lower level of fines in the whey from the 2% fat milk may also contribute to the lower fat losses in this whey; curd fines increase the surface area through which fat is lost from the curd to the whey. The increase in whey fat losses at milk fat >2% may be in part attributed to excessive clumping, which is expected to promote fat coalescence and the formation of free fat that easily permeates the matrix.

Increase of the milk fat content did not significantly influence the percentage protein in the bulk whey. In contrast, the percentage of protein in the white whey decreased significantly on increasing the fat content of the milk from 0.54 to 3.33% (wt/wt). This trend may be in part a consequence of the dilution effects of the increased percentages of fat and salt in the whey (based on salt recoveries in the cheese, Table 6) as the fat content of the milk increased. However, differences among the losses of protein were not significantly (P < 0.05) influenced by milk fat content (expressed as a percentage of the total milk protein) in either bulk or white wheys.

Recoveries of Milk Fat, Protein, and Salt in Cheese

In Table 5 are the mass balance analyses for total weight and the weights of milk fat and protein in three trials, in which all inputs and outputs were measured, including the white whey. The recovery of the total weight of inputs and fat ranged from ~99.1 to 100.8% and was not influenced by milk fat content. However, the total protein recovered from the low-fat milk was significantly lower than that from the reduced-fat or full-fat milks. No good explanation can be offered for the latter trend.

Fat recovery in the cheese increased significantly as the milk fat was increased from 0.5 to 2.0% (wt/wt) and decreased thereafter (Table 6). This trend concurred with the opposite trend noted for the percentage of total milk fat lost in the cheese whey. The protein recovered in the LFC cheese was significantly lower than that in the RFC and FFC cheeses. A tentative explanation for the lower protein recovery in the LFC cheese may be the lower total recovery of protein during the manufacture of this cheese, as revealed by mass balance analysis (Table 5).

We found no relationship between the amount of salt recovered in the cheese and milk fat content (Table 6).

Cheese Yields

The yields of cheeses are given in Table 7. Actual yield increased linearly with milk fat because of the
pro-rata increase in the content of cheese-recoverable solids (i.e., mainly fat plus casein) (Figure 3). The rate of increase in actual yield with milk fat (i.e., 1.16 ± 0.15 kg/kg) indicated that fat contributed more than its own weight to actual yield. A similar observation was made by Gilles and Lawrence (13). This effect was due mainly to the concomitant increase in the content of moisture associated with the cheese protein, as reflected by positive relationship between milk fat content and MNFS (Figure 2). The weight of moisture in the cheese obtained from 100 kg of milk increased with milk fat content at a rate of 0.24 ± 0.05 kg/kg (Figure 4). However, the weight of fat in the cheese obtained from 100 kg of milk also increased with increasing content of milk fat at a rate higher (0.90 ± 0.03 kg/kg; Figure 5) than that for moisture. Hence, the percentage of cheese moisture decreased as milk fat content increased (Table 3).

Similar to the trend observed for actual yield, dry matter cheese yield also increased with increasing milk

Figure 2. The effect of milk fat content on the compositional parameters of Cheddar cheese: moisture (□), moisture in the nonfat substance (MNFS) (■), protein (○), fat in dry matter (FDM) (●), ash (▲), and solids nonfat nonprotein as a fraction of total fat and protein (△).
TABLE 4. The effect of milk fat content on the weights and compositions of cheese wheys.

<table>
<thead>
<tr>
<th>Replicates (no.)</th>
<th>Milk fat content (% wt/wt)</th>
<th>Composition</th>
<th>SED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.54</td>
<td>1.50</td>
</tr>
<tr>
<td>Bulk whey Fat, % wt/wt</td>
<td>6</td>
<td>0.10a</td>
<td>0.21b</td>
</tr>
<tr>
<td>Protein, % wt/wt</td>
<td>6</td>
<td>1.02a</td>
<td>1.04a</td>
</tr>
<tr>
<td>Fines, mg/kg of whey</td>
<td>6</td>
<td>227ab</td>
<td>246a</td>
</tr>
<tr>
<td>White whey Fat, % wt/wt</td>
<td>3</td>
<td>0.18c</td>
<td>0.54bc</td>
</tr>
<tr>
<td>Protein, % wt/wt</td>
<td>3</td>
<td>1.08a</td>
<td>1.00ab</td>
</tr>
<tr>
<td>Fines, mg/kg of whey</td>
<td>3</td>
<td>605a</td>
<td>651a</td>
</tr>
<tr>
<td>Losses Bulk whey Bulk whey/100 kg of milk, kg</td>
<td>6</td>
<td>92.86a</td>
<td>91.63b</td>
</tr>
<tr>
<td>Fat, % of total milk fat</td>
<td>6</td>
<td>17.63a</td>
<td>13.28b</td>
</tr>
<tr>
<td>Protein, % of total protein</td>
<td>3</td>
<td>24.45a</td>
<td>24.93a</td>
</tr>
<tr>
<td>White whey White whey/100 kg of milk, kg</td>
<td>3</td>
<td>0.84b</td>
<td>0.99ab</td>
</tr>
<tr>
<td>Fat, % of total milk fat</td>
<td>3</td>
<td>0.31b</td>
<td>0.39b</td>
</tr>
<tr>
<td>Protein, % of total protein</td>
<td>3</td>
<td>0.28a</td>
<td>0.31a</td>
</tr>
</tbody>
</table>

Values within a row not sharing a common superscript differ (P < 0.05).

Table 5 contains similar data for Cheddar cheese types.

fat content (Figure 3) but at a lower rate (i.e., 0.93 ± 0.10 kg/kg of milk fat). The difference between the rates of increase in actual yield and dry matter cheese yield per unit weight of milk fat (i.e., 0.23 kg/kg of milk fat) was due to the dry matter cheese yield eliminating the contribution of moisture to cheese yield, which increased at a rate of 0.24 ± 0.05 kg/kg of milk fat.

The increase in dry matter cheese yield per kilogram of milk fat was greater than that expected based on the corresponding increase in the weight of cheese fat per kilogram of milk fat (i.e., 0.90 ± 0.03 kg/kg; Figure 5). The difference (i.e., 0.03 kg/kg of milk fat) in the rates of increase between dry matter cheese yield and weight of fat in cheese, per unit weight of fat in the milk, was a consequence of the increased weight of soluble SNFP (i.e., dissolved substances such as lactate, whey protein N, soluble salts, glyco-macro peptide, and sodium chloride) in the cheese as the fat content increased. As previously discussed, the quantity of cheese moisture per 100 kg of milk increased significantly as the milk fat content increased (Figure 4). However, the direct contribution of fat to dry matter cheese yield was less than its own weight in milk due to the loss of fat in cheese whey (−11% total).

Comparison of Actual and Predicted Cheese Yields

Actual yield was compared with predicted yield, as calculated using the original Van Slyke formula (Equa-
TABLE 6. The effect of milk fat content on recoveries of fat, protein, and added salt in Cheddar cheese.

<table>
<thead>
<tr>
<th>Milk fat content (% wt/wt)</th>
<th>Recovery, % of that in milk</th>
<th>Fat</th>
<th>Protein</th>
<th>Salt</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.54</td>
<td>80.84b</td>
<td>74.57b</td>
<td>58.87a</td>
<td></td>
</tr>
<tr>
<td>1.50</td>
<td>87.16ab</td>
<td>75.17ab</td>
<td>60.58a</td>
<td></td>
</tr>
<tr>
<td>2.00</td>
<td>89.48a</td>
<td>75.73a</td>
<td>61.67a</td>
<td></td>
</tr>
<tr>
<td>3.33</td>
<td>87.84ab</td>
<td>75.53a</td>
<td>61.07a</td>
<td></td>
</tr>
</tbody>
</table>

Values presented are the means of 6 replicates.

Table 5.

**Table 7.** The effect of milk fat content on actual and dry matter cheese yields.

<table>
<thead>
<tr>
<th>Milk fat content (% wt/wt)</th>
<th>Actual yield1</th>
<th>DM yield2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.54</td>
<td>6.37d</td>
<td>3.43d</td>
</tr>
<tr>
<td>1.50</td>
<td>7.49f</td>
<td>4.29f</td>
</tr>
<tr>
<td>2.00</td>
<td>8.09b</td>
<td>4.79b</td>
</tr>
<tr>
<td>3.33</td>
<td>9.50a</td>
<td>5.92a</td>
</tr>
</tbody>
</table>

Values presented are the means of 6 replicates.

**Table 5.**

**Table 6.**

Values within a row not sharing a common superscript differ \((P < 0.05)\).

1SE D = standard error of difference; degrees of freedom = 15.

### Discussion

In the current study, pasteurization of milk resulted in 6.0 to 8.0% denaturation of the total whey protein with the content of milk fat having no significant effect. This degree of denaturation resulted in an average increase in actual yield of 0.066 kg/100 kg of milk for the FFC cheese and 0.12 kg/100 kg for the HFC cheese. These results were similar to those of Lau et al. (29), who reported that 5% of the total whey protein was denatured on batch pasteurization (63°C × 30 min) and contributed an increase of 0.01 to 0.04 kg/100 kg of milk in theoretical Cheddar cheese yield. It was assumed that all denatured whey protein was complexed with \(\kappa\)-CN and was retained in the cheese. The yields predicted on the basis of casein content of the unpasteurized milk were significantly lower \((P < 0.05)\) than the corresponding actual yields with the difference augmenting as the milk fat content decreased. Predicted yield coincided with actual yield at milk fat contents of 2.9 to 3.0% (wt/wt); at lower and higher milk fat contents, predicted yield became increasingly lower and higher, respectively. To elucidate the reasons for the discrepancy between actual yield and predicted yield, the contributions of the following factors to cheese yield were investigated: 1) denaturation of whey proteins on pasteurization (29), 2) differences in fat recovery in the cheese as affected by milk fat content (Table 5), and 3) the increase in SNFP with reduction in milk fat content (Table 3).

In the current study, pasteurization of milk resulted in 6.0 to 8.0% denaturation of the total whey protein with the content of milk fat having no significant effect. This degree of denaturation resulted in an average increase in actual yield of 0.066 kg/100 kg of milk for the FFC cheese and 0.12 kg/100 kg for the HFC cheese. These results were similar to those of Lau et al. (29), who reported that 5% of the total whey protein was denatured on batch pasteurization (63°C × 30 min) and contributed an increase of 0.01 to 0.04 kg/100 kg of milk in theoretical Cheddar cheese yield. It was assumed that all denatured whey protein was complexed with \(\kappa\)-CN and was retained in the cheese. The yields predicted on the basis of casein content of the unpasteurized milk were significantly lower \((P < 0.05)\) than those predicted using casein as a percentage of total protein of the pasteurized milk for all cheeses. This finding suggests that, when using the original Van Slyke formula, a more accurate yield prediction is obtained if a modification is included to incorporate a contribution for whey protein denatured by milk pasteurization. Replacement of the term C—0.1 in Equation [1] with the term Cum—0.1 + WPum (% WPDpm/100) resulted in a predicted cheese yield that was closer to, but still significantly lower than, actual yield for LFC cheese, numerically lower for HFC and RFC cheeses, and significantly higher for the FFC (Figure 6b). In the latter term, um = unpasteurized milk, and pm = pasteurized milk. The mean values for the WPum (% WPDpm/100) in FFC, RFC, HFC, and LFC milks were 0.043, 0.048, 0.043, and 0.038, respectively. When determining the contribution of WPum (% WPDpm/100) to the predicted yield, the mean value for each fat category was used.

In the original Van Slyke formula for FFC, the coefficient for fat recovery was 0.93. However, in the current study the percentage fat recovery varied with milk fat content. Hence, the coefficient 0.93 in Equation [1] was replaced by the mean value of percentage fat recovery/
100 for each fat category (Table 6). The mean values for percentage fat recovery in cheeses FFC, RFC, HFC, and LFC were 87.84, 89.48, 87.16, and 80.84, respectively. Although little information is available on the percentage fat recovery in Cheddar cheeses with less than normal fat content, the value for the FFC was similar in magnitude to that obtained by others (6, 29). This finding suggested that the coefficient of 0.93 in Equation [1] might be an overestimation, depending on milk composition, manufacturing process, and plant design (6, 10). On modifying Equation [1] to include the corrections for whey protein denaturation and fat recovery, the regression line for predicted yield attained a slope (1.26 kg of cheese/kg of milk fat) closer to that (1.16 kg of cheese/kg of milk fat) of the regression line for actual yield. However, the predicted yields were significantly lower than \( P < 0.05 \) actual yields (Figure 6c).

Reduction in the fat content of the cheese was paralleled by higher contents of SNFP (Table 3). The coefficient 1.09 for 1+ SNFP in Equation [1] for FFC cheese underestimated the contribution of SNFP to the yield of Cheddar cheeses with lower than normal fat content. Hence, the coefficient 1.09 in Equation [1] was replaced by the mean value of 1 + SNFP for each fat category. The average SNFP values for FFC, RFC, HFC, and LFC cheeses were 0.10, 0.11, 0.13, and 0.16, respectively (Table 3). Modification of Equation [1], as in Equation [2] below, to include the corrections for whey protein denaturation, fat recovery, and SNFP, reduced the differences between actual and predicted yields:

\[
Y_P = \left[ \frac{F \times \% \text{FRC}}{100} + (CN - 0.1) + \left( \text{WPum} \times \% \text{WPDpm} \times \frac{1}{100} \right) \right] \times (1 + \text{SNFP})
\]

\[
\text{where } F = \text{percentage fat in the milk; } \% \text{FRC} = \text{percentage fat recovery; } CN = \text{percentage milk casein, calculated using casein as a percentage of total protein of the unpasteurized milk and the starter inoculum (as discussed in materials and methods); WPum = undenatured whey protein of the unpasteurized milk; } \% \text{WPDpm} = \text{percentage whey protein denatured on pasteurization; } 1 + \text{SNFP} = \text{a coefficient to account for cheese solids nonfat nonprotein; and } Md = \text{reference moisture content. The slopes of the regression lines for actual yield and the predicted yield (using Equation [2]) were equal at 1.16 kg of cheese/kg of fat in milk (Figure 6d).}

In the current study, the mean values of the coefficients WPum (% WPDpm/100), % FR/100, SNFP, and MD for each fat category were used in Equation [2]. However, replacement of the mean coefficient values with those for the individual vats had no significant effect on the cheese yield predicted using Equation [2] (Figure 7). The mean difference between actual and predicted yields, as determined using average values for the coefficients, were 0.13 (SD = 0.08), 0.17 (SD = 0.12), 0.13 (SD = 0.08), and 0.15 kg of cheese/100 kg of milk.
milk (SD = 0.05) for FFC, RFC, HFC, and LFC cheeses. The corresponding differences using individual vat coefficients were 0.11 (SD = 0.07), 0.12 (SD = 0.09), 0.09 (SD = 0.09), and 0.1 kg of cheese/100 kg of milk (SD = 0.08).

Use of Equation [2] with the appropriate coefficients for whey protein denaturation, percentage fat recovery/100, and SNFP (as determined in the current study) enables the yields of Cheddar cheeses with fat contents ranging from 7 to 33% (wt/wt) to be predicted with reasonable accuracy. The coefficients in Equation [2] are influenced by many parameters in practice including, stage of lactation, genetic variant of κ-CN, somatic cell count, diet, vat design, curd firmness at cutting, and cutting programs (1, 5, 30, 31). More precise prediction of the yield of Cheddar cheeses of different fat contents at the commercial level would require plantspecific values for these coefficients to be used in Equation [2].

CONCLUSIONS

Increase of the fat content in the milk from 0.54 to 3.33% (wt/wt), while maintaining the casein content relatively constant, affected Cheddar cheese composition, fat recovery, and cheese yield. These findings highlighted the importance of standardizing milk to a fixed casein to fat ratio on year-round basis, especially when using a seasonal milk supply of varying composition (2, 4, 9, 34). Variations in the fat content, or more precisely casein to fat ratio, can occur, in practice, because of

Figure 5. Effect of milk fat content on the weight (kg) of cheese fat obtained from 100 kg of milk.

Figure 6. Effect of milk fat content on the actual (—□—) and predicted (— — —) yields of Cheddar cheeses of different fat contents. Actual yield compared with yield predicted by Van Slyke’s formula using the casein of the unpasteurized milk (a); actual yield compared with yield predicted by Van Slyke’s formula using the casein of the pasteurized milk (b); actual yield compared with yield predicted by Van Slyke’s formula modified to include the contributions for whey protein denaturation and fat recovery (c); and actual yield compared with yield predicted by Van Slyke’s formula modified for whey protein denaturation, fat recovery, and solids nonfat nonprotein (d) (see Equation [2] in text).
stage of lactation, plane of nutrition, differences in somatic cell counts, health status of cow, duration of cold storage, and efficiency of standardization practices (5, 14, 33, 35).

Predicted yields calculated using the original Van Slyke formula were significantly lower than the corresponding actual yields for LFC, HFC, and RFC cheeses. The discrepancy between actual and predicted yields was attributed to the contribution of whey protein denaturation on pasteurization and to differences in the percentage fat recovery and content of SNFP between cheeses of different fat contents. Modification of the original Van Slyke formula to include the contributions of the latter parameters enabled a more accurate prediction of the yield of Cheddar cheeses of different fat contents.

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REFERENCES


