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Effect of uncertainty in composition and weight measures in control of cheese yield and fat loss in large cheese factories

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ABSTRACT

Our objective was to develop a computer-based cheese yield, fat recovery, and composition control performance measurement system to provide quantitative performance records for a Cheddar and mozzarella cheese factory. The system can be used to track trends in performance of starter cultures and vats, as well as systematically calculate theoretical yield. Yield equations were built into the spreadsheet to evaluate cheese yield performance and fat losses in a cheese factory. Based on observations in commercial cheese factories, sensitivity analysis was done to demonstrate the sensitivity of cheese factory performance to analytical uncertainty of data used in the evaluation. Analytical uncertainty in the accuracy of milk weight and milk and cheese composition were identified as important factors that influence the ability to manage consistency of cheese quality and profitability. It was demonstrated that an uncertainty of ±0.1% milk fat or milk protein in the vat causes a range of theoretical Cheddar cheese yield from 10.05 to 10.37% and an uncertainty of yield efficiency of ±1.5%. This equates to ±1,451 kg (3,199 lb) of cheese per day in a factory processing 907,185 kg (2 million pounds) of milk per day. The same is true for uncertainty in cheese composition, where the effect of being 0.5% low on moisture or fat is about 484 kg (1,067 lb) of missed revenue opportunity from cheese for the day. Missing the moisture target causes other targets such as fat on a dry basis and salt in moisture to be missed. Similar impacts were demonstrated for mozzarella cheese. In analytical performance evaluations of commercial cheese quality assurance laboratories, we found that analytical uncertainty was typically a bias that was as large as 0.5% on fat and moisture. The effect of having a high bias of 0.5% moisture or fat will produce a missed opportunity of 484 kg of cheese per day for each component. More accurate rapid methods for determination of moisture, fat, and salt contents of cheese in large cheese factories will improve the accuracy of yield performance evaluation and control of consistency of cheese composition and quality.
Key words: yield, fat loss, theoretical yield, cheese

INTRODUCTION

Perhaps the most important factors affecting the efficiency of cheese production are milk composition and milk quality. Milk composition influences cheese yield and varies seasonally and regionally (Barbano, 1990). Higher milk fat and casein content translates into more fat and casein that can be incorporated into the cheese, assuming a low milk psychrotrophic bacteria count (Hicks et al., 1982) and a low milk SCC (Barbano et al., 1991; Barbano, 1996; Klei et al., 1998).

The Van Slyke formula has been used for over 100 yr to predict theoretical Cheddar cheese yield (Van Slyke and Publow, 1909) allowing Cheddar cheese yield to be predicted at any given moisture based on the fat and casein content of the milk used. The VanSlyke theoretical cheese yield formula for Cheddar cheese is as follows:

$$\text{Yield} = \frac{\left[\left(\text{milk fat \%} \times 0.93\right) + \left(\text{milk casein \%} - 0.1\right) \times 1.09\right]}{1 - \left(\text{target cheese moisture} / 100\right)},$$

where 0.93 represents a fat recovery in the cheese of 93%, (milk casein % − 0.1) represents a fixed amount of casein lost in whey that is equivalent to about 0.1% casein, and 1.09 is a factor that accounts for a salt level of 1.7% and the retention of nonfat, noncasein milk solids in Cheddar cheese with about 37% moisture.

Although accurate predictions of theoretical Cheddar cheese yield (Barbano and Rasmussen, 1992) have been reported, the 1.09 value in the Van Slyke formula does not correctly predict yield for reduced-fat Cheddar or other types of cheeses when fortified milk is used for cheese making. Because of these shortcomings, a more generalized theoretical cheese yield equation was created.

The Barbano theoretical yield formula contains parameters that allow the user to predict yield across a

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variety of different cheeses, target compositions, and whey draining pH values (Rudan et al., 1999; Metzger et al., 2000). The Barbano theoretical cheese yield formula is as follows:

$$\text{Theoretical cheese yield} = (A + B + C)/\{1 - [(\text{target cheese moisture} + \text{target cheese salt})/100]\},$$

where A is the milk fat recovered in the cheese:

$$A = [\%\ \text{fat in the milk} \times (\%\ \text{fat recovery in cheese}/100)];$$

B is the milk casein plus calcium phosphate recovered in the cheese:

$$B = [(\%\ \text{casein in the milk} - 0.1) \times \text{calcium phosphate retention factor}];$$

and C is the other milk solids recovered in the cheese (i.e., nonfat, noncasein, non-calcium phosphate–milk solids):

$$C = \{[(A + B)/(1 - \text{actual cheese moisture}\ \%/100)] - (A + B) \times (\text{separated whey solids}\ \%/100)\} \times (\text{solute exclusion factor}).$$

A fat recovery target of 93% has been accepted as an achievable target for Cheddar (Van Slyke and Publow, 1909). A fat recovery of 84 to 85% was suggested for mozzarella, according to Barbano (1996) and Rudan et al. (1999). However, due to improved mozzarella cheese manufacturing technology, fat recoveries of between 85 and 90% can be expected. In a theoretical yield formula, the recovery parameters are fixed and reflect best-case achievable performance. The VanSlyke and Barbano formulas were used and compared in a nonlinear programming optimization model to maximize net revenue in cheese and whey product manufacture (Papadatos et al., 2002).

The Barbano theoretical yield formula contains parameters A, B, and C, which allow it to predict theoretical yield for any type of cheese using any composition of milk. The A represents the fat recovery in the cheese, B represents the casein and calcium phosphate retention in the cheese, and C represents the retention of nonfat whey solids in the water phase of the cheese. The target moisture and salt content of the cheese are specified in the equation. The accuracy of the formula is limited by the milk composition data (fat and protein/casein) and separated whey solids measurement accuracy.

Many large cheese factories use rapid secondary methods for analysis of cheese. Near-infrared (**NIR**) spectroscopy is commonly used for cheese analysis; NIR calibrations require 200 to 400 cheese samples with accurate reference chemistry values for each cheese type that are created using partial least squares (**PLS**) models for each NIR instrument (McKenna, 2001; Barbano and Lynch, 2006). Producing accurate reference chemistry on a large number of cheese samples for each type of cheese produced in that factory is a challenge because the factory laboratories no longer run large numbers of reference tests on cheese. As a result, the accuracy of the reference chemistry may be weak, resulting in poor NIR prediction calibration for moisture and fat, which leads to incorrect management decisions that affect the company's financial performance.

The objectives of our work were to demonstrate a method to evaluate cheese yield performance and identify sources of cheese yield loss, particularly fat losses, by using well-established cheese yield relationships in large cheese manufacturing factories and to determine the sensitivity of the outcome of the evaluation to uncertainty in various input parameters.

MATERIALS AND METHODS

Computer Software Platform Used for the Study and General Organization

A computer-based cheese yield, fat recovery, and composition control performance evaluation system was developed using an Excel 2010 (Microsoft Corp., Redmond, WA) spreadsheet to provide quantitative performance records for a Cheddar and mozzarella cheese factory. In an Excel workbook, worksheets are separated in different tabs and used in this study as an example, but a database program could also be developed using the same analytical approach and equations. An explanation of all equations is given below.

It is common for large Cheddar cheese factories to produce different varieties of Cheddar and related cheeses (e.g., Colby, Monterey jack, washed curd, low- or reduced-fat Cheddar) or for mozzarella cheese factories to produce a range of *pasta filata* cheese varieties (e.g., whole milk, part skim, low moisture, provolone). Each variety of cheese is called a "cheese type" and could be made with different starter culture strains and have different cheese composition targets and control limits. The Excel workbook (one for each month of the year) was developed with multiple worksheets within the monthly workbook. Three worksheets (i.e., tabs) contain the default parameters: one for setting default