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Predicting cottage cheese cutting time using a light backscatter sensor

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An optical light backscatter sensor was investigated as a device to determine the cutting time of cottage cheese. A complete randomized block design with 3 repeats was used to study the impact of different gelation temperatures (23, 27 and 32 °C) and starter concentrations (0.50, 2.75, and 5.00%) on gelation. A low concentration of rennet (2 ppm) was also added and gelation was monitored using an in-line light backscatter sensor operated at 880 nm and the gel cutting time of milk was visually evaluated. Linear regression between the cutting time (t_{cut}) and various parameters collected from the light backscatter ratio profile (and its first and second derivatives) were used to generate prediction equations. The simple equation, $t_{cut} = \beta_0 + \beta_1 t_{2max2}$, using the light backscatter parameter t_{2max2} , the time to the second minimum of the second derivative of the light backscatter ratio profile, predicted cutting time with a standard error of prediction (SEP) of 6.28 min and R^2 of 0.997 within the wide range of gelation rates tested. Light backscatter parameters are useful for prediction of cutting under the wide range of processing conditions tested for cottage cheese manufacture.

Voraussage über die Schneidezeit von Cottagekäse mit Hilfe eines Licht-Rückstreuungsverfahren-Sensors

Eine optischer Licht-Rückstreuungsverfahren-Sensor wurde als Vorrichtung zur Bestimmung der Schneidezeit von Cottagekäse geprüft. Ein vollständig randomisiertes Blockdesign mit 3 maliger Wiederholung wurde eingesetzt, um die Auswirkung unterschiedlicher Gelierungstemperaturen (23, 27 und 32°C) und Säureweckerkonzentrationen (0,50, 2,75 und 5,00%) auf die Gelbildung zu prüfen. Eine geringe Labkonzentration (2 ppm) wurde ebenfalls eingesetzt und die Gelierung mit einem in-line Licht-Rückstreuungsverfahren-Sensor bei 880 nm verfolgt. Die Gelschneidezeit wurde visuell bewertet. Die lineare Regression zwischen Schneidezeit (t_{cut}) und anderen von dem Licht-Rückstreuungsverfahren-Verhältnisprofil (und seinen ersten und zweiten Ableitungen) gesammelten Parametern wurde zur Entwicklung von Voraussagegleichungen verwendet. Die einfache Gleichung $t_{cut} = \beta_0 + \beta_1 t_{2max2}$, die den Licht-Rückstreuungsverfahren-Parameter t_{2max2} und die Zeit bis zum zweiten Minimum der zweiten Ableitung des Licht-Rückstreuungsverfahren-Verhältnisprofils verwendet, sagte die Schneidezeit mit einem SEP von 6,28 min und R^2 von 0,997 innerhalb des weiten Bereiches der untersuchten Gelierungsraten voraus. Licht-Rückstreuungsverfahren-Parameter sind von Bedeutung für die Voraussage des Schneidens im weiten Bereich der für die Herstellung von Cottagekäse untersuchten Verarbeitungsbedingungen.

55 Cottage cheese (predicting cutting time)

55 Cottagekäse (Voraussage der Schneidezeit)

1. Introduction

Traditionally, cottage cheese has been made by bacterial fermentation of skim milk with or without rennet addition. The cutting time (t_{cut}) for this type of cheese depends on factors such as milk composition, gelation temperature and calcium, enzyme (rennet) and starter (inoculum) concentrations. The temperature and inoculum concentration can be easily manipulated, which allow the testing of cutting time prediction under a wide range of gelation rates. Several authors have indicated that a precisely defined gel cutting time significantly affects yield and texture properties of cottage cheese (1, 2, 3). Therefore, being able to accurately select the cutting time for milk gels during cheese making is a significant factor to improve final product quality and consistency.

There has been extensive amount of research focused on monitoring the phenomena of milk coagulation and cutting time prediction (4, 5, 6). A number of devices like vibrational probe, rheometer, hot wire and optical sensor have been tested for predicting cutting time (7), but only a few references have been found regarding monitoring gel formation in cottage cheese (3, 8, 9, 10, 11). Cottage cheese gels are formed primarily as a result of acid production by the starter culture as well as some contribution by rennet if a low concentration

(few ppm) of this optional ingredient is used. Light backscatter in the near-infrared wavelength range (650–1200 nm) measures the steadily increasing size of aggregates during coagulation. However, because of the variability of cottage cheese making conditions, where starter cultures and slow rennet activity are involved, the light backscatter profile must be analyzed to determine robust correlations that provide an accurate cutting time prediction over the wide range of conditions typically encountered during manufacture. The objective of this study was to investigate the light backscatter response during cottage cheese manufacturing as affected by temperature and inoculum concentration to obtain information for exploiting this cutting time prediction technology.

2. Materials and methods

2.1 Milk sample preparation for coagulation tests

Low-heat skim milk powder (Dairy America, Fresno, CA) with 6.51 mg g⁻¹ of undenatured whey protein nitrogen (12) was dispersed in deionized water to prepare a 10% (w/w) total solids solution. Reconstituted milk samples had a protein content of 3.83 ± 0.01% and were fortified with CaCl₂ to a concentration of 0.2 g/kg and

heated at 63 °C for 30 min. After heating, milk was rapidly cooled in ice water and stored at 4 °C overnight until use. The milk sample was preheated to the desired temperature before inoculation for each experiment. Starter culture was prepared 13 h before the experiment by fermenting 0.5% (w/w) mesophilic lactic acid starter (Chr. Hansen, Ready Set 98, Milwaukee, WI) in sterilized skim milk (~10% of total solids) at 25 °C until pH 4.8 as described by CASTILLO *et al.* (8). The detailed procedures for reconstitution of the milk and the data acquisition process are shown in Fig. 1.

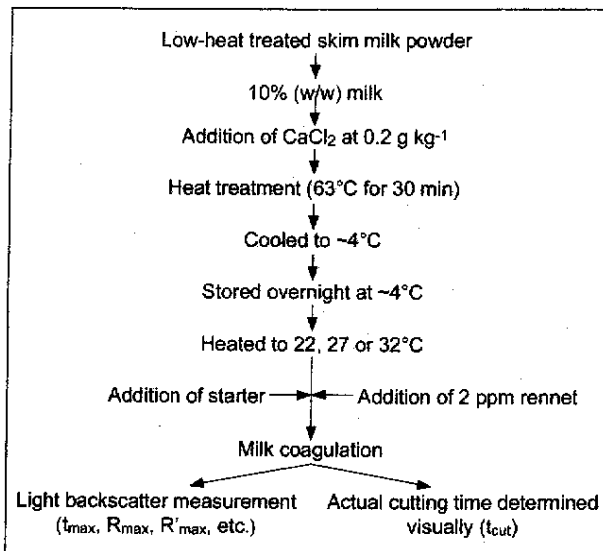


Fig. 1: Flow diagram of model cottage cheese gelation and data acquisition processes.

2.2 Milk coagulation monitored by light backscatter sensor

Two liters of milk were placed in a mini-vat, which had a light backscatter sensor mounted on the vat wall. The entire unit was placed in a water bath at the desired incubation temperature. The starter culture was added at time = 0 min and then the 2 mg/kg rennet (CHY-MAX® Extra, Chr. Hansens, Milwaukee, WI) was added at time = 5 min. The milk was stirred for 30 s to ensure thorough mixing of milk, starter and enzyme. Coagulation of milk was then monitored by starting the Co-AguLite software of the backscatter sensor (Reflectronics Inc, Lexington, KY), as described by CASTILLO *et al.* (8).

2.3 Visual cutting time determination

When the milk gel was approaching its cutting time, a round end glass rod (7 mm in diameter and 20 cm in length), was used to assist in the determination of cutting time. The glass rod was placed vertically in the middle of the milk gel with 8 cm height of rod above the gel surface, which ensured that it was easy to judge the curd rigidity near the cutting time. When the glass rod could maintain its vertical position for a short period of time (~3 s), a spatula was then used to cut the milk gel. The final cutting time was determined whenever the cut surface of milk gel was smooth and had clean edges.

2.4 Data analysis

Data were analyzed using the multivariable regression procedure of Statgraphics version 5.0 (Manugistics, Inc, Rockville, MD) to predict the visually determined cutting time from the light backscatter parameters. Analysis of variance was performed using the multifactor ANOVA procedure of Statgraphics.

3. Results and discussion

An ANOVA for t_{cut} was conducted to determine the main sources of variation in variables. Effects of gelation temperature and inoculum concentration were statistically significant ($p < 0.001$) for t_{cut} (Table 1).

The Pearson's correlation coefficients of all the parameters collected from the light backscatter sensor are compared in Table 2. Significant ($p < 0.05$) correlations between t_{cut} and time based parameters (t_{max} , t_{2max} , t_{2min} , and t_{2min2}) were observed, which justified the usefulness of time-based parameters as cutting time predictors. The detailed information for the parameter definitions is given in previous work (9).

Table 1: Analysis of variance and F-statistics for cottage cheese cutting time¹

Source	DF	Sum of squares	F-value
Model	3	289472	74.722
Replicate	1	324	0.253
Gelation temperature	1	192407	148.992
Inoculum concentration	1	96741	74.912
Error	23	29702	
Corrected total	26	319174	

¹General linear model here includes replicates as another factor; DF, degree of freedom; sum of squares, Type III; F-value, ANOVA F-statistic. ²Significant at $p < 0.01$ level. ³Not significant at $p = 0.1$ level.

Table 2: Pearson correlation coefficients between various backscatter variables¹

	t_{2max}	T_{max}	Time based parameters			t_{cut}	Reflectance based parameters
			t_{2min}	t_{2max2}	t_{2min2}		
t_{cut}	0.607 ³	0.587 ³	0.585 ³	0.583 ³	0.551 ⁴		
R'_{max}	-0.826 ²	-0.840 ²	0.841 ²	-0.844 ²	-0.863 ²	-0.058 ^{ns}	
R_{max}	-0.825 ²	-0.839 ²	0.841 ²	-0.843 ²	-0.862 ²	-0.056 ^{ns}	
R'_{min}	-0.818 ²	-0.832 ²	0.833 ²	-0.835 ²	-0.855 ²	-0.043 ^{ns}	
R_{min}	-0.826 ²	-0.841 ²	0.842 ²	-0.844 ²	-0.864 ²	-0.058 ^{ns}	
R'_{max2}	-0.828 ²	-0.842 ²	-0.843 ²	-0.845 ²	-0.865 ²	-0.060 ^{ns}	
R_{min2}	-0.824 ²	-0.838 ²	-0.839 ²	-0.842 ²	-0.861 ²	-0.075 ^{ns}	
R_{cut}	0.404 ^{ns}	0.427 ^{ns}	0.428 ^{ns}	0.435 ^{ns}	0.472 ⁴	-0.358 ^{ns}	Highly correlated except for R_{cut}

¹N=27; ² $p < 0.001$; ³ $p < 0.01$; ⁴ $p < 0.05$, ^{ns}not significant. Detailed information on the definition of parameters is given by CASTILLO *et al.* (9).

Table 3: Regression models for the prediction of cutting time¹

Model	β_0	β_1	β_2	β_3	R ²	SEP (min)
I $t_{cut} = \beta_0 + \beta_1 t_{2max2}^2$	13	1.02	—	—	0.99	6.28
II $t_{cut} = \beta_0 + \beta_1 t_{2min2}^3$	-4.43	1.03	—	—	0.99	6.63
III $t_{cut} = \beta_0 + \beta_1 t_{2max2}^2 + \beta_2 t_{2min2}$	3.02	0.53	0.50	—	0.99	3.98
IV $t_{cut} = \beta_1 R_{max2}^4 + \beta_2 t_{2max2}^2 + \beta_3 t_{2min2}$	2.28	35997	0.72	0.30	0.99	3.03
V $t_{cut} = \beta_0 + \beta_1 T + \beta_2 [S] + \beta_3 T^2 [S]^5$	1128.8	-24.97	-74.74	1.56	0.91	33.83

¹N = 27; $\beta_0, \beta_1, \beta_2, \beta_3$, regression coefficients; SEP, standard error of prediction. ² t_{2max2} is the time at second maximum of second derivative of reflectance ratio profile (R). ³ t_{2min2} is the time at second minimum of second derivative of reflectance ratio profile (R). ⁴ R_{max2} is the first maximum of second derivative of reflectance ratio profile (R). ⁵T = temperature; [S] = starter concentration.

3.1 Effect of gelation temperature and inoculum concentration on gelation properties

Temperature affects gelation in several ways, including starter growth rate (10, 13), enzyme reaction rate (14, 15), thermal motion of caseins and the rearrangement of casein particles (11, 16). Since acidification and gelation was significantly influenced by temperature and inoculum concentration, a model (model V in Table 3) was developed that incorporated temperature and inoculum concentration to describe cutting time. Figure 2 is a response surface plot based on model V and shows the effect of gelation temperature and inoculum concentration on visually determined cutting time. ANOVA analysis indicates that gelation temperature and inoculum concentration had statistically significant ($p < 0.001$) effects on the cutting time. The interaction between these two variables was also significant ($p < 0.05$).

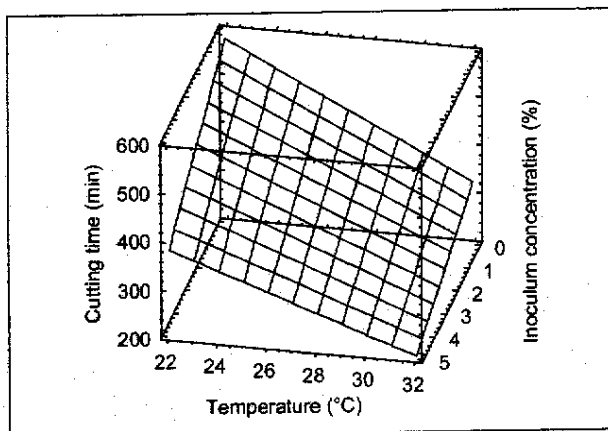


Fig. 2: Response surface plot of the effect of gelation temperature and inoculum concentration on cutting time (t_{cut}) by model V.

3.2 Cutting time prediction

Selection of the best, [i.e. highest R² and lowest standard error of prediction (SEP)], 1, 2 and 3 variable prediction models for t_{cut} was performed. The independent variables (gelation temperature and inoculum concentration) together with dependent variables (various light backscatter parameters) were tested. Table 3 summarizes the best-fit models for prediction of t_{cut} . Model I, which predicts the cutting time solely with the time based parameter t_{2max2} , had a R² of 0.997 and SEP of 6.28 min. This model agrees with previous research (10), where t_{2max2} was selected as the best single parameter when cutting time was set as a constant pH value (pH = 4.8). The time based parameter t_{2min2}

was also a potential objective parameter for predicting t_{cut} , in terms of R² and SEP (Model II). Since t_{2min2} is sometimes difficult to determine precisely (from back scatter profiles), other parameters within the t_{max} to t_{cut} time range, which corresponds to the gel assembly period (11), were also examined for their prediction ability. Model III was a combination of t_{2max2} and t_{2min2} . The approximately equal value of the regression coefficients, β_1 and β_2 , indicates the equal importance of t_{2max2} and t_{2min2} in the prediction, as shown in Models I and II. The R² value was improved and SEP was reduced to 3.98 min in Model III by compared to Model I or II. By including in Model III the response parameter, R_{max2} , reduced the SEP from 3.98 to 3.03 min (Model IV), but was not practical for in-plant operation because it would require the determination of 3 regression coefficients rather than two. Models including more parameters were not included due to their complexity and impracticality for in-line operation at a cheese manufacturing plant.

4. Conclusions

Cottage cheese type gelation over a wide range of gelation rates (different temperatures and inoculum concentrations) were monitored by a light backscatter sensor and several of these optical parameters were used to predict the cutting time (i.e. pH = 4.8). Irrespective of the temperature and inoculum concentration used, the cutting time could be accurately predicted using parameters solely derived from the optical sensor with a standard error of prediction from 3.03 to 6.63 min. The use of a light backscatter sensor appears to be a promising method for accurately predicting the cutting time of a cottage cheese type gel system.

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