Texture development in cheddar cheese during ripening

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1Agricultural and Biological Engineering Department, The Pennsylvania State University, University Park, PA, USA 16802; 21839 Blackhawk Dr., Grafton, WI, USA 53024; and 3Department of Nutrition and Food Sciences, Utah State University, Logan, UT, USA 84322-8700. Received 26 April 1999; accepted 25 August 1999.

Iruadayaraj, J., Chen, M. and McMahon, D.J. 1999. Texture development in cheddar cheese during ripening. Can. Agric. Eng. 41:253-258. Texture development during ripening of full-fat (FFCC) and reduced-fat (RFCC) cheddar cheese was studied with respect to the key reactive groups related to protein, fat, and moisture. Spectra of the mid-infrared region was obtained using the Fourier transform infrared (FTIR) spectrometer. Texture parameters such as hardness, cohesiveness, gumminess, adhesiveness, chewiness, and springiness were determined by texture profile analysis and correlated with the key protein, fat, and moisture related chemical groups. R-square values obtained for hardness, adhesiveness, and springiness for FFCC were 0.67, 0.54, and 0.75 while the values for RFCC were 0.51, 0.59, and 0.54 respectively. Hardness and gumminess increased while cohesiveness and springiness of FFCC and RFCC changed slightly during aging. Adhesiveness decreased with aging time for the two cheeses. Multiple regression analysis was used to estimate texture parameters as a function of key reactive groups related to protein, fat, and moisture. Keywords: texture profile analysis, FTIR spectroscopy, cheddar cheese, ripening.

Des études furent faites sur les changements de texture durant le mûrissement du fromage cheddar avec une teneur régulière (FFCC) et réduite en gras (RFCC) en ce qui concerne les groupes chimiques des protéines, des gras et de l’humidité. A l’aide d’un spectromètre infrarouge à transformée de Fourier, on obtint le spectre dans la région de l’infrarouge moyen. Les paramètres de texture comme la dureté, la cohésion, la tendance à coller, l’adhésion, la résistance à la dent et l’élasticité furent déterminés selon la méthode d’analyse du profil textural et corrélos avec l’élément clé des groupes chimiques des protéines, des gras et de l’humidité. Pour le Cheddar à teneur en gras régulière, les valeurs de R-carré pour la dureté, la tendance à adhérer et l’élasticité étaient de 0.67, 0.54 et 0.75, alors que pour le fromage à teneur réduite en gras, elles étaient de 0.51, 0.59 et 0.54, respectivement. Durant la période de mûrissement, la dureté et la tendance à coller ont augmenté alors que la cohésion et l’élasticité des deux types de fromage ont peu changé. La tendance à adhérer a diminué durant la période de mûrissement pour les deux Cheddars. Des analyses de régression multiples ont été faites pour estimer les paramètres de texture en fonction de l’élément clé des groupes chimiques des protéines, du gras et de l’humidité.

INTRODUCTION

Texture development during aging of cheese occurs in two phases (Lawrence and Gillies 1987). Phase one constitutes the first 7-14 days when the rubbery texture of young cheese is rapidly converted to a smoother, more homogenized product as a result of the break down of αs-1-casein. Phase two (14 - 90 days) involves a more gradual change in texture over the months as a result of continuing break down of αs-1-casein and other caseins. During ripening, casein, specifically the αs-moietiy is hydrolyzed first, whereas β- and ρ-κ-casein are not greatly proteolysed in most bacteria-ripened cheeses (Nauth and Ruffie 1995).

The structural matrix of cheese is a cross-linked casein-calcium phosphate network in which fat globules are physically entrapped (Prentice 1987). Scanning electron micrographs indicate that the nature of the protein matrix influences texture attributes (Bryant et al. 1995). Hardness and springiness increase with decreasing fat content. The protein matrix is elastic when the casein is largely intact, but its elasticity is lost during proteolysis. The entrapped fat globules in the matrix serve to limit deformation of the elastic cheese matrix, and their size distribution is a function of the breed of cow and shear history of the milk (Jameson 1990).

Texture is an important characteristic of Cheddar cheese in deciding consumer acceptability and quality (McEwan et al. 1989). It is known that reduction in fat content usually results in excessively firm and elastic (often described as "rubbery") or hard, dry, and possibly grainy cheese. Due to the relative deficiency of fat globules there is more structural matrix per unit cross-sectional area in reduced-fat cheeses (Emmons et al. 1980), which tend to accelerate syneresis during cheese manufacture.

Many investigators have studied the effect of cheese composition and protein breakdown on rheological measurements of various types of cheese (Chen et al. 1979; Fedrick et al. 1986). Lawrence et al. (1983) pointed out that differences in texture at any particular stage of ripening depend on the differences in basic structure and the extent to which the basic structure has been modified. Studies by Johnson and Chen (1995) point to the fact that firmness of cheese may not be controlled solely by its composition but also by the level of proteolysis that occurs during ripening. The products of proteolysis, i.e., amino acids and peptides and compounds derived from them are known to contribute to texture and flavor of cheese (both desirable and undesirable).

FTIR technique has been widely used to determine fat, protein, and moisture contents of butter, milk, and other high fat products (van de Voort et al. 1992a, 1992b, 1993). Other applications include monitoring the oxidation of edible oils (van de Voort et al. 1994) and the determining the level of trans unsaturation in fats (Ulberth and Haider 1992). Quantitative and qualitative assessments can be made by examining specific bands corresponding to functional chemical groups in the mid-infrared region. Statistical correlation methods are not always
necessary, although they are not excluded and may be required in very complicated mixtures (Belton et al. 1987). The use of FTIR spectroscopy for qualitative measurements of cheese is limited, primarily because of the difficulties in sampling procedure. However, recent work by Chen et al. (1998) demonstrates a simple FTIR technique for cheese analysis.

Lawrence and Gillies (1987) studied the relationship of texture and rheological properties in relation to composition, pH, salt level, and rennet used. However, limited work has been done on texture development in full-fat Cheddar cheese (FFCC) and reduced-fat Cheddar cheese (RFCC) and its relevance to chemically reactive groups. If a model for texture can be developed then texture, composition, and chemical group characteristics can be simultaneously obtained by one measurement. The specific objectives of this study were to 1) examine the difference in texture between FFCC and RFCC during ripening; and 2) quantify texture parameters in terms of the change in key functional chemical groups corresponding to fat and protein.

**MATERIALS and METHODS**

**Milk and cultures**

Skim milk from the Gary H. Richardson Dairy Products Laboratory at Utah State University (Logan, UT) was standardized to 3.6% and 1.8% fat with cream using Pearson's equation to produce FFCC and RFCC. The C.S.S. Bulk Set Dairy cultures (mesophilic lactic acid producing cocci; CT-C, lot 961131) from Waterford Foods Inc. (Millville, UT) were used for cheese. The concentration of the inoculum in the culture was 0.5% and the incubation temperature was 30°C. The culture was grown in low fat milk (2%) for about 5 h before its use.

**Cheddar cheese manufacturing procedure**

FFCC (31.3% fat content) and RFCC (21.4% fat content) were made in three separate vats in the Gary H. Richardson Dairy Products Laboratory at Utah State University (Logan, UT). The manufacturing procedures for FFCC and RFCC were as described by Chen et al. (1998).

**Proximate analysis**

The percentage compositions of fat, protein, and moisture were determined using the methods outlined in Standard Methods for the Examination of Dairy Products (Marshall 1993). Fat content was determined using the Babcock method (method 15.8d), moisture content by vacuum oven method (method 15.10A), and protein content using the Kjeldahl method (method 15.12A). All samples were tested in triplicate.

**Fourier transform infrared (FTIR) spectroscopy analysis**

Small samples (15 mm in height and 15 mm in diameter) were cut from the center of a cheese block and frozen for at least 2 h at -80°C. The frozen sample was sliced to thin slices of 16 μm thick using a IM236 microtome (International Equipment Co., Needham Heights, MA). The sliced film was then placed on the surface of a silver chloride crystal in the light path of the Bio-Rad FTS-7 FTIR spectrometer (Bio-Rad, Digitlab Division, Cambridge, MA) equipped with a deuterated triglycine sulphate (DTGS) detector. The samples were allowed to equilibrate for at least 10 min and spectra of samples in the region between 4000 and 400 cm⁻¹ were obtained with a resolution of 4 cm⁻¹ and a scanning frequency of 32 scans/sample. The spectra of cheese samples were collected at ripening times of 1, 2, 3, 4, 6, 8, 10, 14, 18, 23, and 28 weeks. Peak area of selected reactive groups in the spectra corresponding to protein and fat was obtained using the peak report option of the Bio-Rad Win-IR software (Bio-Rad, Cambridge, MA).

**Texture profile analysis (TPA)**

Texture tests were conducted using a 25.4 mm diameter cylindrical probe. Cylindrical samples 15 mm in diameter and 15 mm in height (Jack et al. 1993) were used in texture experiments. These samples were large enough to represent the whole block but small enough to minimize inclusion of structural irregularities (Prentice 1992) that affect the tests. All the samples were cut at 4°C using a cork borer to prevent barreling of the cylinders. The samples were obtained from the middle of the whole cheese block rather than from the surface to avoid surface effects.

The samples were allowed to equilibrate at room temperature for 1 h in a closed container (Marshall 1990) before texture experiments. The TPA option of the Steven Farnells QTS-25 texture analyzer was used for measuring texture properties of cheese using an interactive windows based QTS software. Texture analysis was conducted at the same time as the FTIR analysis. Speed of the probe was set at 10 mm/min and the deformation was kept at 20%. All TPA tests were conducted at room temperature in replicates of five. Texture parameters monitored included hardness, cohesiveness, adhesiveness, gumminess, chewiness, and springiness were recorded.

**Statistical analysis**

The correlation of texture parameters and spectral absorbance of reactive groups (corresponding to the protein and fat) at specific wavelengths was determined. Multiple linear regression analysis was used to quantify cheese hardness, springiness, and adhesiveness using stepwise regression. Statistical Analysis System (SAS Inc., Cary, NC) was used for all data analysis.

**RESULTS and DISCUSSION**

**TPA analysis**

Hardness, the force necessary to attain a given deformation, is one of the important factors in determining cheese texture (Bryant et al. 1995). Reduction of fat content in cheese increased the hardness (Fig. 1). The decrease in hardness during the early stages of ripening is due to the initial rubbery texture of young cheese curd, which rapidly transforms into a smoother, and a more homogeneous product due to proteolysis of the casein network. This casein network is greatly weakened when only a single bond in about 20% of the α₁-casein is hydrolyzed by the coagulant to give the peptide α₁I (Creamer and Olson 1982).

The increase in hardness after 4-6 weeks is mainly due to the availability of water during proteolysis (Lawrence et al. 1983). During proteolysis as each peptide bond is cleaved, two new ionic groups are generated which compete for the available water in the system. Thus, water previously available for solvation of the protein chains will become associated to the new ionic groups. Relatively low moisture cheese, such as Cheddar, tends therefore to become increasingly harder with
Table I. Proximate composition of full-fat and reduced-fat cheddar cheese.

<table>
<thead>
<tr>
<th>Content</th>
<th>Sample and composition (%) (mean ± stdev)</th>
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<tbody>
<tr>
<td></td>
<td>FFCC</td>
</tr>
<tr>
<td>Fat</td>
<td>31.3 ± 0.2</td>
</tr>
<tr>
<td>Protein</td>
<td>17.2 ± 0.3</td>
</tr>
<tr>
<td>Moisture</td>
<td>38.5 ± 0.8</td>
</tr>
<tr>
<td>Ash</td>
<td>2.7 ± 0.4</td>
</tr>
<tr>
<td>Ph</td>
<td>5.7 ± 0.2</td>
</tr>
<tr>
<td></td>
<td>RFCC</td>
</tr>
<tr>
<td>Fat</td>
<td>21.4 ± 0.2</td>
</tr>
<tr>
<td>Protein</td>
<td>21.8 ± 0.3</td>
</tr>
<tr>
<td>Moisture</td>
<td>42.4 ± 0.4</td>
</tr>
<tr>
<td>Ash</td>
<td>3.4 ± 0.2</td>
</tr>
<tr>
<td>Ph</td>
<td>5.8 ± 0.2</td>
</tr>
</tbody>
</table>

Fig. 1. Hardness of FFCC and RFCC during ripening.

Fig. 2. Cohesiveness of FFCC and RFCC during ripening.

Fig. 3. Gumminess of FFCC and RFCC during ripening.

Adhesiveness, which is defined as the work necessary to overcome attractive forces between the contacted (surface of cheese) and the contacting (surface of probe) material decreased slightly with fat content (Fig. 4). RFCC contains increased amount of protein which alters the protein matrix, making it more compact and, therefore, less adhesive, alternatively more cohesive. Both RFCC and FFCC aged for 6 months were less adhesive (Fig. 4). A similar trend was observed by Bryant et al. (1995) in their study on low-fat cheese wherein the authors reported lower values of adhesiveness in cheese ripened for up to 4 months. During ripening, in addition to proteolysis, there is also a movement of
al. (1995) observed that reduced fat cheese (13-27% fat content) were springier than full fat (32-34%) cheese when compressed to 55% of its original height. Emmons et al. (1980) demonstrated that low-fat Cheddar cheese was springier than full-fat Cheddar cheese and concluded that reducing fat content will result in fewer fat globules with more casein present per unit volume as evidenced by electron micrographs. A possible reason could be that the 20% deformation used in the TPA experiment is not sufficient. At 20% deformation, the fat and protein present are mechanically exerted within their elastic limit and irrespective of the fat content will exhibit a similar behavior. However, when higher deformation values are used, the behavior of these constituents extend to the plastic state, and fat being more pliable than protein tends to impart a higher degree of springiness to higher fat cheeses. Chewiness, the product of hardness, cohesiveness, and springiness increased with age and decreased with fat content. Overall trend was similar to that of hardness because of its strong interdependence (Fig. 6).

Correlation between TPA and FTIR data
Texture parameters of FFCC and RFCC were correlated with the absorbance of peak areas corresponding to the reactive groups of fat, protein, and water in Cheddar cheese. Hardness had a better correlation with the peak absorbance area of bands at 1167, 1461, 1744, and 2850 cm\(^{-1}\) for FFCC and at 1116, 1640-1650, 1744, and 2850 cm\(^{-1}\) for RFCC. The correlation coefficients corresponding to the respective wavenumbers were 0.66, 0.62, 0.60, and 0.44 for FFCC and 0.25, 0.32, 0.26, and 0.28 for RFCC. The difference in hardness is highly correlated (Correlation coefficient = 0.66) to the band at 1167 cm\(^{-1}\) arising from C-O stretch (due to fat and protein) for FFCC instead of the band at 1640-1650 cm\(^{-1}\) arising from protein amide I and bound water for RFCC (Surewicz and Mantsch 1988; van de Voort et al. 1992a). During ripening, fat content, hydrolysis products of proteolysis, and water available for solvation of protein chains, all contribute to the development of hardness.
The overall protein content in cheese plays a significant role in hardness; however, in FFCC, the presence of fat affects this property to a greater extent. The maximum R-square value obtained by regressing hardness with predominant reactive groups (corresponding to fat, protein, and moisture) using stepwise regression is 0.67 for FFCC and 0.51 for RFCC (Table II).

Table II. Coefficient of correlation between hardness and peak absorbance area corresponding to each reactive group for FFCC and RFCC.

<table>
<thead>
<tr>
<th>Peak Frequency (cm⁻¹)</th>
<th>Related functional groups</th>
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<tbody>
<tr>
<td>1116</td>
<td>C-N &amp; C-C stretch</td>
</tr>
<tr>
<td>1167</td>
<td>C-O stretch</td>
</tr>
<tr>
<td>1240</td>
<td>C-C &amp; C-N stretch</td>
</tr>
<tr>
<td>1461</td>
<td>-CH₂X, X=CO, O, N, OCO</td>
</tr>
<tr>
<td>1744</td>
<td>R(CO)X, X= O', OR, H, R</td>
</tr>
<tr>
<td>2850</td>
<td>R(CH₃)R</td>
</tr>
<tr>
<td>2930</td>
<td>CH₃R</td>
</tr>
<tr>
<td>1530-1540</td>
<td>amide I (peptide bond)</td>
</tr>
<tr>
<td>1640-1650</td>
<td>random portion</td>
</tr>
<tr>
<td>1653-1658</td>
<td>helical portion</td>
</tr>
</tbody>
</table>

FFCC_{Hardness} = 248.61 + 14.56 A_{1116} + 71.83 A_{1167} - 92.26 A_{1240} + 22.45 A_{1461} - 7.36 A_{1744} + 2.10 A_{2850} - 5.91 A_{2930} - 4.03 A_{1640-1650} \ [R^2=0.67; \ \sqrt{MSE} = 87.91]

RFCC_{Hardness} = 591.31 - 55.87 A_{1116} - 92.20 A_{1167} + 18.69 A_{1240} + 70.43 A_{1744} - 7.03 A_{2850} - 27.10 A_{2930} + 68.04 A_{1640-1650} \ [R^2=0.51; \ \sqrt{MSE} = 214.96]

The spectra data may not completely capture the complex physical and biochemical changes that occur during cheese ripening. Higher values of R² could be observed if larger data set and longer aging times are used in conjunction with non-linear statistical analysis to incorporate interactions.
Examination of proteolysis by capillary electrophoresis revealed an increase in the concentration of non-protein nitrogen due to the hydrolysis of the casein protein in FFCC and RFCC (Chen et al. 1998). Incorporation of electrophoresis data in the texture model will also help to improve the correlation and understanding of texture in cheese.

CONCLUSIONS

Hardness of full-fat and reduced-fat Cheddar cheese during aging increased with ripening time. The hardness for RFCC was greater than that of FFCC due to the reduction in fat and an increase in protein content. Fat and moisture content had a greater effect than protein on springiness of cheese. The higher protein content in RFCC altered the protein matrix, making it more compact and therefore less adhesive. Adhesiveness had the lowest correlation with the functional groups (R-square value was 0.54 for FFCC and 0.59 for RFCC). Relative R-square values of statistical models for texture were in general higher for FFCC (R^2 = 0.75 for springiness) compared to RFCC (R^2 = 0.59 for adhesiveness). The work presented is one of the first attempts in characterizing cheese texture in terms of key reactive groups in the mid-infrared range. Improved texture models can be developed by additional experimentation with ripening times and applying non-linear statistical analysis. The correlation models could be used with the quantitative and qualitative chemical information from FTIR spectra to develop multi-component sensing systems.

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