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The relationships between the chemical, rheological and textural properties of Cheddar cheese*

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Summary — Descriptive analysis techniques were used to train a panel to identify and measure the perceived textural properties of 17 samples of Cheddar cheese of different age and origin. An Instron Universal Testing Machine integrated with Instron Series XI Materials Testing Software was used to measure true rheological properties. Fat, pH, moisture, and salt content were determined using standard techniques. The relationships between the sensory, rheological and chemical data were investigated using multiple regression techniques in an attempt to produce models for predicting the sensory attributes of Cheddar. Accurate models were constructed for the majority of the sensory attributes using the rheological measures (r^2 = 0.52–0.9). A model for creaminess could only be constructed using the percentage fat and moisture content variables and no accurate model could be produced for crumbliness by chewing. The most accurate models were for those attributes measured using the fingers and the least accurate were for the mouthfeel characteristics.

Cheddar / cheese / texture / rheological property / sensory property

Résumé — Relations entre les propriétés chimiques, rhéologiques et la texture du fromage cheddar. Des techniques d'analyses descriptives ont été employées pour former un groupe de dégustateurs, afin d'identifier et mesurer la texture perçue de 17 échantillons de fromage cheddar d'âges et d'origines différents. Une machine universelle de traction-compression (Instron) avec son logiciel (Instron Series XI Materials Testing Software) a été utilisée pour mesurer les qualités physiques authentiques. Matière grasse, pH, humidité et sel ont été déterminés selon des techniques courantes. Les relations entre les données sensorielles, physiques et chimiques ont été étudiées en utilisant des techniques de régression multiple, pour essayer de produire des modèles prédisant les attributs sensoriels du cheddar. Des modèles précis ont été construits, pour la plupart des attributs sensoriels, en appliquant les mesures rhéologiques (r^2 = 0,52–0,9). Un modèle pour la texture crémeuse n'a pu être construit qu'en utilisant les variables de matières grasses et d'humidité ; il a été impossible de produire un modèle exact de friabilité par mastication. Les modèles les plus exacts ont été ceux des qualités mesurées par les doigts, et les moins exacts ceux qui sont déterminés par mastication.

cheddar / fromage / texture / propriété rhéologique / propriété sensorielle

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INTRODUCTION

Texture has been identified by consumers as an important characteristic in many foods (Szczesniak, 1971), which is especially true for cheese where its texture is widely recognised as one of the most important attributes in determining both its identity and quality (Creamer and Olson, 1982; Jack et al, 1993). Reliable methods enabling the measurement of cheese texture are therefore a pertinent requirement for the cheese industry.

In the cheese industry texture assessment is traditionally the responsibility of an expert cheese grader. Following several years of training and experience the grader can accurately assess the textural quality of a cheese based on a few simple sensory measures involving the manipulation of a cylinder of cheese cut from the matured block (Bodyfelt et al, 1988). Unfortunately textural attributes are communicated by a vocabulary of terms which appear ambiguous and are even misunderstood between the graders themselves (Prentice, 1987). This ambiguity becomes increasingly problematic when the terms used by sensory panels and consumers are also interpreted differently again.

Extensive sensory assessment of cheese texture has been carried out using the General Foods Sensory Texture Profile Analysis technique (Brandt et al, 1963). This method requires long training periods and the textural attributes measured are predefined. More recently researchers (Colwill, 1989; McEwan et al, 1989; Piggott and Mowat, 1991; Muir and Hunter, 1992; Muir et al, 1995) have adopted descriptive analysis techniques which allow the panel to generate and define their own terms which are then generic to the food product being tested.

Instrumental measurements of food texture are based on the food's rheological properties. These properties are measured by instruments that deform a food sample in some manner whilst recording the forces applied and the resulting deformation.

Assessment of cheese texture has been performed using the General Foods Instrumental Texture Profile Analysis on the Instron Universal Testing machine (Chen et al, 1979; Patel et al, 1991; Jack et al, 1993). This technique was developed along side their sensory technique and the texture measurements taken correspond to those assessed using the palate.

Such empirical techniques have been criticised (Bagley and Christianson, 1987) as the measures taken are poorly defined and are dependent on the instrument and test method employed.

Fundamental methods entail the measurement of a food material's precise rheological properties. These measures can be described mathematically and the results are returned in standard units of measurement. As a consequence these measures are clearly defined and are not restricted to the test instrument or test method employed (Muller, 1973). Recently the majority of instrumental tests performed on cheese have involved compressing the sample using an Instron or similar apparatus, with the rheological properties reported in terms of the force-deformation curve (Zoon, 1991). Zoon (1991) suggests that if studies concerning the relationship between instrumental and sensory properties are to be compared then they should report the rheological properties in terms of the stress-strain curve.

The majority of compressive tests carried out on food materials involve large deformations. The relative, or engineering, strain is widely used in instrumental measurement of food texture (Calzada and Peleg, 1978). However, this does not take into account the fact that height and width of the specimen change considerably as it is compressed such that the engineering strain and stress levels measured are significantly different from the true strain and true stress (Calzada and Peleg, 1978).

Compositional indices have long been recognised in the dairy industry as indicators of cheese quality such that moisture and acidity levels are constantly monitored and controlled during its production (Bodyfelt et al, 1988).

All of the main components of Cheddar cheese — protein, fat and water (brine) — affect its rheological behaviour and, therefore, its textural properties. Its structure is composed of a protein (casein) matrix interspersed with fat globules and water, some of which is bound to the casein molecules (Prentice, 1987). The casein network is formed mainly from helical chains which gives the matrix a certain level of elasticity. The Cheddaring process leads to the production of a structure composed of fibrous protein molecules which results in a very close textured cheese (Jack and Paterson, 1992). The extent to which the matrix can be deformed is restricted by the amount of fat, and to some extent, the amount of moisture present. Increased moisture levels will also increase the elastic recovery after deformation (Jack and Paterson, 1992).

The salt content and pH level affect the texture of Cheddar cheese indirectly. The proteolysis of the casein network is dependent on the salt-in-moisture concentration (percentage S/M) and the pH level. Low percentage S/M levels have been found to produce a 'weak' and 'pasty' Cheddar whereas high concentrations produce an excessively 'firm' body (Prentice, 1987). As the pH decreases the breakdown of the protein network increases which gives rise to a variety of textures within a small pH range. Lawrence et al (1987) reported that at around pH 5.4 Cheddars are 'springy' and 'plastic' whereas at a pH of 4.9 they are much 'shorter' and 'less cohesive'.

Ultimately consumers judge quality on the basis of their own sensory perceptions, not instrumental readings. However, the use of instruments may provide a more objective and cost effective method of measuring cheese texture if relationships can be established between chemical and/or rheological parameters and sensory measures (Szczesniak, 1987).

Research has been carried out into the relationships between the chemical, sensory and instrumental measures of texture and, although relationships have been discovered, no two pieces of research appear to use the same methods and/or test parameters. The aim of this study was to investigate the relationship between the chemical, rheological and perceived textural properties of Cheddar cheese. The objective was to investigate the possibility of developing mathematical models using combinations of the chemical and/or rheological parameters which could be used routinely to predict the perceived textural characteristics of Cheddar cheese.

MATERIALS AND METHODS

Seventeen commercially available Cheddars exhibiting a wide range of maturity and textural properties were used for this study (table I). Both block-formed and farmhouse varieties were included in addition to two low fat Cheddar substitutes.

Chemical analysis

The chemical analyses were carried out on five replicates of each Cheddar sample.

The percentage moisture and fat content were determined by the AOAC Distillation method 969.19 (AOAC, 1990) and the Gerber Process (British Standard Council, 1989) respectively.

A Corning 926 Chloride analyser was utilised to calculate the percentage salt content. A grated 1 g sample of Cheddar was macerated with 100 mL of distilled water and then centrifuged for 1 min at 2000 rpm to remove the debris. The analyser carries out an electronic titration of the chloride ions present in a 0.5 mL specimen which is then converted to a percentage salt measurement.

Table I. Commercial Cheddar samples* and their approximate ages.

Ages approximatifs des échantillons de cheddar commerciaux.*

Cheddar	*Approximate age (months)*
English Mild	4
Irish Medium	8
Tasty	11
Canadian	21
Sturminster Newton	9
Quickes Extra Mature	17
Irish Mild	6
English Medium	9
Vintage Wexford	22
Irish Mature	14
Somerset	6
Cricketers Low Fat	9
Scottish Medium	9
English Mature	14
Shape Mature	9
Quickes Farmhouse	9
3-month-old English Cheddar	3

* Cheddar names are those attributed to the cheese for commercial sale by the manufacturer.

* *Les noms de cheddar sont les noms de commercialisation.*

The pH level was detected using a Unicam spearheaded combination electrode and Jenway pH meter with a temperature probe attached. The electrode and probe were placed in a 10 mL beaker packed with finely grated Cheddar sample. The electrode was cleaned with detergent after every five measurements to remove the fat build-up that may have otherwise interfered with the results.

Rheological properties

The rheological properties were derived from force-deformation curves obtained using an Instron Universal Testing Machine, model 1140, integrated with the Instron Series IX Materials Testing software package. A compression test using a 5 kg load cell and 45 mm compression anvil was performed using a crosshead speed of 50 mm/min on five replicates of each Cheddar sample. The cheese samples used were cylindrical, measuring 19 mm diameter by 26 mm, cut at 4 °C to prevent barrelling and were equilibrated at 20 °C for 1 h prior to testing. This was the average room temperature of the laboratory in which testing occurred but is also a similar temperature used by recent researchers in this field (Emmons et al, 1980; Green and Marshall, 1985; Jack et al, 1993) thus making comparisons with their work possible.

The rheological parameters measured were True Stress, True Strain and Work to both the yield and fracture points and also the True Young's Modulus. Figure 1 shows a typical True Stress-True Strain curve for Cheddar cheese and the points at which the measurements were taken.

The True Strain (also known as Hencky Strain) was calculated according to equation 1 (Calzada and Peleg, 1978):

$$\varepsilon = \ln H_o / (H_o - \Delta H) \quad (1)$$

where ε = true strain; H_o = original height; ΔH = change in height.

The True Stress (σ) was calculated by dividing the force applied by the surface area of the specimen at a specific time $_{(t)}$ as shown in equation 2 (Calzada and Peleg, 1978):

$$\sigma_{(t)} = F_{(t)} / A_{(t)} \quad (2)$$

where $\sigma_{(t)}$ = true stress at time $_{(t)}$; $F_{(t)}$ = force at time $_{(t)}$; $A_{(t)}$ = area at time $_{(t)}$.

The Stress and Strain data obtained from the Instron model 1140 do not take into account the changes that occur in the specimen dimensions as

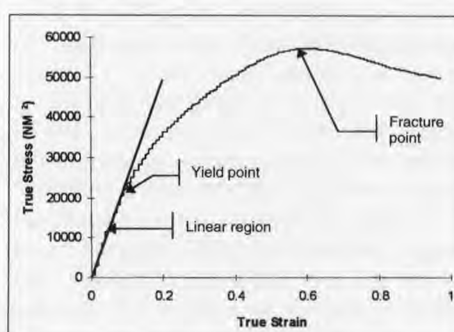


Fig 1. Typical stress strain curve for Cheddar cheese.

Exemple de courbe contrainte-déformation pour le cheddar.

it is compressed. Poisson's ratio for Cheddar cheese is equal to 0.5 (Muller, 1973) indicating that as a cylindrical specimen is compressed its diameter increases and height decreases with no change in volume. Consequently there is a simple relationship between the sample height and its diameter. The area $A_{(t)}$ can, therefore, be estimated using the Instron data.

Sensory methods

Descriptive analysis procedures (Lyon et al, 1992) were used to define and quantify the perceived textural properties of Cheddar cheese.

Training

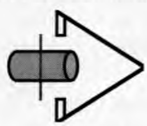
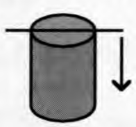
The sensory panel consisted of nine members of University staff. They were chosen on the basis of their ability, interest and availability to participate in 12 1-h training sessions to prepare them to evaluate the textural properties of Cheddar cheese.

The panel was presented with a wide range of Cheddar samples in order to generate a list of terms that they would use to describe the textural attributes that they perceived. A list of 21 terms was reduced during discussion to seven well-defined descriptors (table II). The methods used to detect these attributes were also defined (table III) and decisions were made to measure

Table II. Agreed descriptors and definitions for the perceived textural attributes of Cheddar cheese.
Descripteurs et définitions des paramètres de texture du cheddar.

Descriptor	*Definition*
Creaminess	The extent to which the cheese has a velvety mouthfeel
Crumbliness	The extent to which the sample breaks when chewed or compressed
Firmness	The force required to compress the cheese with the fingers
Graininess	The extent to which the cheese is bitty towards the end of chewing
Hardness	The force required to penetrate the cheese with a knife or the teeth
Springiness	The extent to which the cheese springs back when compressed

Table III. Testing methods employed by assessors.
Méthodes d'évaluation utilisées par le jury.

Test by	*Testing method*
Fingers	Place cylinder between thumb and fore finger and squeeze
First Bite	Place cylinder between teeth and bite into half way along
	 Bite here
Cutting	Stand the cylinder on its end and cut down the centre:
	 Cut here
Chewing	Chew half the cylinder bitten off as in First Bite

hardness by cutting and on first bite, and also to measure crumbliness with the fingers and whilst chewing.

The remaining training sessions involved the assessors practising the use of continuous line scales to develop their ability to repeatedly quantify the intensity of the different attributes. The scales increased in intensity from left to right for each attribute and the word anchors used at either end were decided upon by the panel.

The sensory data from the preliminary training sessions were examined for those panellists whose scoring consistently fell more than two standard errors from the mean for each attribute. These panellists were informed of their inconsistencies so that they could adjust their scoring to the panel norms. Sensory data obtained from the remaining training sessions were subjected to a one-way analysis of variance and least significant difference tests to identify any assessors who were scoring differently to the rest of the panel ($P = 0.05$). Two assessors were consistently scoring differently for the majority of the attributes and were removed from the panel.

Testing

During each testing session four Cheddar samples were evaluated by each assessor for all the attributes. The sessions were organised so that replicate judgements were obtained from all the assessors for each of the seventeen Cheddar samples.

Each individual cheese sample consisted of five cylinders of cheese identical to those used for the rheological tests. The order of presentation of the samples to each assessor was randomised using a partial Latin square design. The assessors were also provided with record sheets, a palate cleanser (water), a round bladed knife, an instruction sheet and a copy of the attribute definitions.

The attributes for each sample were quantified on continuous line scales identical to those used in the training sessions.

Statistical analysis

Statistical analysis of the data was performed using SPSS for Windows Release 6.1 (SPSS Inc. 444 North Michigan Ave, Chicago, IL 60611).

One-way analysis of variance procedures were performed to ascertain whether the chemical, rheological and sensory parameters were able to differentiate between the different Cheddar samples. The Pearson's correlation coefficients were calculated between all the parameters to determine whether relationships existed between them. The individual relationships between the sensory variables and remaining parameters were investigated more closely for linearity using scatter plots. Where scatterplots revealed non-linear relationships logarithmic transformations were applied.

The relationship between the sensory characteristics and the rheological parameters of the cheeses was investigated using multiple regression. A 'Stepwise' option (Anon, 1993) was chosen as the method for deciding which variables were to be included in the regression equation. All the variables, or transformed variables where required, were available for inclusion in the equation. In some cases, rather than relying totally on the algorithm used by SPSS to select variables, additional variables were forced into the equation to see if the relationship could be improved. Such variables were only left in the equation if there was a marked improvement to the relationship (table VIII).

The predicted values for the sensory attributes for each of the Cheddar samples were calculated using the relevant model suggested by the stepwise regression analysis (table VIII). These data were then plotted against the actual sensory results to allow closer inspection.

RESULTS

The mean results and standard deviations for the chemical, rheological and sensory variables are given in tables IV, V and VI, respectively. All the variables revealed significant differences between the majority of the Cheddar samples ($P \leq 0.05$) thus warranting further investigation.

The correlation coefficients revealed strong interrelationships between each of the sensory attributes, apart from creaminess, and also between many of the Instron variables. Strong correlations also existed between the percentage moisture and fat content ($r = -0.95$) and the percentage salt content and pH (r = 0.87). No significant relationships were revealed between the rheological and chemical parameters.

The results indicated that relationships existed between the instrumental variables, except work-to-yield, and most of the sen-

Table IV. Chemical composition of Cheddar samples.
Composition chimique des échantillons de cheddar.

Cheddar	*Moisture content (%)*	*Fat content (%)*	*pH*	*Salt content (%)*
English Mild	38.53	34.20	5.05	1.92
sd	1.18	0.45	0.02	0.05
Irish Medium	36.67	32.52	5.16	1.92
sd	0.62	0.38	0.01	0.06
Tasty	35.93	35.10	5.25	1.87
sd	0.25	0.22	0.01	0.03
Canadian	34.8	36.24	4.91	1.77
sd	0.40	0.39	0.02	0.05
Sturminster Newton	36.92	34.22	5.21	1.88
sd	0.19	0.30	0.01	0.06
Somerset	34.32	35.70	5.15	1.99
sd	0.34	0.27	0.01	0.06
Irish mild	37.77	31.33	5.38	2.26
sd	0.36	0.40	0.03	0.05
English Medium	38.19	31.84	5.26	1.89
sd	0.34	0.42	0.02	0.09
Wexford	37.68	32.96	5.16	2.10
sd	0.74	0.60	0.02	0.09
Irish Mature	37.3	31.16	5.11	1.94
sd	0.93	0.53	0.01	0.06
Quickes Extra Mature	31.06	38.40	5.65	2.43
sd	0.11	0.65	0.02	0.06
Cricketers Low Fat	44.46	22.38	5.21	2.05
sd	0.64	0.57	0.00	0.06
Scottish Medium	35.97	35.22	5.02	1.89
sd	0.73	0.35	0.01	0.05
English Mature	37.99	33.52	5.12	1.89
sd	0.45	0.60	0.02	0.07
Shape Low Fat	45.94	16.52	5.30	2.23
sd	0.66	0.48	0.01	0.05
Quickes Farmhouse Mature	35.65	36.90	5.4	2.33
sd	0.46	0.17	0.01	0.09
Three-month-old	34.69	36.80	5.48	2.37
sd	0.51	0.27	0.01	0.04

Figures are means and standard deviations of five replicates.
Les valeurs représentent les moyennes et écarts types de cinq répétitions.

sory attributes, a selection of which are listed in table VII.

Relationships between the chemical and sensory parameters were limited to the creaminess variable which showed some correlation with the percentage moisture ($r = -0.5$; $P = 0.04$) and the percentage fat content ($r = 0.61$; $P = 0.01$).

Table V. Rheological properties of Cheddar samples.
Propriétés rhéologiques des échantillons de cheddar.

Cheddar	*True Stress at Yield (MPa)*	*True Strain at Yield*	*True Stress at Fracture (MPa)*	*True Strain at Fracture*	*True Young's Modulus (MPa)*
English Mild	0.044	0.074	0.078	0.370	0.706
sd	0.003	0.008	0.002	0.070	0.114
Irish Medium	0.046	0.113	0.079	0.543	0.644
sd	0.003	0.021	0.010	0.016	0.088
Tasty	0.051	0.053	0.095	0.262	1.017
sd	0.005	0.003	0.012	0.018	0.157
Canadian	0.063	0.065	0.089	0.144	0.965
sd	0.007	0.011	0016	0.012	0.303
Sturminster Newton	0.527	0.056	0.067	0.106	0.976
sd	0.014	0.008	0.021	0.033	0.210
Somerset	0.064	0.098	0.082	0.250	0.638
sd	0.009	0.015	0.008	0.044	0.133
Irish mild	0.047	0.144	0.069	0.622	0.476
sd	0.005	0.020	0.002	0.100	0.129
English Medium	0.041	0.127	0.065	0.489	0.403
sd	0.003	0.019	0.007	0.016	0.833
Wexford	0.061	0.060	0.096	0.216	0.987
sd	0.009	0.011	0.007	0.023	0.156
Irish Mature	0.065	0.058	0.108	0.220	1.146
sd	0.004	0.007	0.011	0.007	0.176
Quickes Extra Mature	0.988	0.060	0.120	0.111	1.790
sd	0.258	0.010	0.023	0.012	0.144
Cricketers Low Fat	0.065	0.085	0.102	0.226	0.809
sd	0.007	0.002	0.007	0.023	0.107
Scottish Medium	0.064	0.068	0.097	0.201	1.005
sd	0.005	0.019	0.006	0.017	0.238
English Mature	0.051	0.052	0.092	0.289	0.970
sd	0.004	0.008	0.016	0.019	0.085
Shape Low Fat	0.048	0.101	0.084	0.296	0.548
sd	0.001	0.008	0.005	0.043	0.024
Quickes Farmhouse Mature	0.066	0.064	0.096	0.178	1.200
sd	0.011	0.012	0.019	0.023	0.000
Three-month-old	0.047	0.124	0.067	0.847	0.610
sd	0.003	0.013	0.013	0.283	0.990

Figures are means and standard deviations of five replicates.
Les valeurs représentent les moyennes et écarts types de cinq répétitions.

Table VI. Perceived texture attribute scores for Cheddar samples.
Notes d'analyse des différents paramètres de la texture.

Cheddar	*Creaminess*	*Crumbliness by chewing*	*Crumbliness by fingers*	*Firmness*	*Graininess*	*Hardness by cutting*	*Hardness on first bite*	*Springiness*
English Mild	4.69	2.49	2.34	4.41	2.50	4.63	3.54	4.61
sd	2.32	1.17	0.75	1.53	1.77	1.62	1.68	2.10
Irish Medium	4.71	2.33	1.49	3.30	2.47	3.04	2.49	6.25
sd	2.09	1.42	0.83	1.83	2.26	1.73	1.09	0.73
Tasty	5.16	3.20	3.15	5.40	2.79	5.24	5.45	2.75
sd	1.72	1.72	1.43	1.82	1.72	1.82	1.64	1.17
Canadian	4.24	6.82	7.44	7.74	5.77	5.36	4.89	0.77
sd	2.16	1.39	1.08	0.81	2.14	1.64	2.59	0.61
Sturminster Newton	3.41	7.43	8.25	7.69	7.13	5.06	4.69	0.57
sd	2.16	0.85	0.41	0.90	0.91	2.11	2.79	0.54
Somerset	5.32	2.81	4.54	6.24	3.22	5.47	5.21	2.29
sd	1.12	1.47	2.12	1.44	1.93	1.73	1.41	1.48
Irish mild	4.50	1.69	1.10	1.63	1.15	1.98	1.24	6.26
sd	2.62	1.64	0.87	0.82	0.75	1.14	0.86	2.00
English Medium	5.20	1.09	1.44	1.66	1.81	2.45	1.23	6.63
sd	1.99	0.63	1.12	0.85	1.37	1.17	0.67	1.72
Wexford	5.45	4.10	4.50	5.98	3.92	5.16	4.72	3.67
sd	1.87	1.47	1.44	1.95	1.49	1.64	1.63	2.54
Irish Mature	4.99	2.87	3.95	5.72	3.51	5.47	5.10	3.50
sd	1.88	1.64	1.86	1.76	2.00	1.77	2.32	1.81
Quickes Extra Mature	4.06	6.48	7.05	8.39	7.15	6.32	6.42	0.32
sd	2.74	1.36	0.70	0.61	1.52	1.47	2.24	0.38
Cricketers Low Fat	2.13	7.02	7.16	6.90	5.93	6.35	5.58	2.59
sd	1.20	1.00	1.21	1.57	1.98	1.04	2.53	2.51
Scottish Medium	5.14	3.20	3.95	6.21	4.32	4.50	4.23	3.06
sd	1.54	1.49	2.05	1.82	2.21	1.67	1.38	1.86
English Mature	6.31	2.06	3.01	5.07	2.65	4.18	3.19	3.74
sd	1.94	1.07	1.39	1.85	1.96	0.83	1.32	2.25
Shape Low Fat	1.63	5.41	6.10	5.15	5.71	6.25	5.25	4.13
sd	0.87	1.46	1.99	1.96	2.06	1.06	1.38	1.86
Quickes Farmhouse Mature	6.43	3.01	4.79	5.71	4.76	4.93	3.31	2.45
sd	1.41	1.44	2.09	1.91	2.12	1.47	1.87	1.70
Three-month-old	2.51	5.22	1.98	3.49	4.51	3.12	3.77	6.27
sd	1.67	1.13	1.54	0.85	2.73	0.61	1.88	0.89

Table VII. Pearson's correlation coefficient between selected parameters.
Coefficient de corrélation de Pearson entre paramètres de texture.

	Crumbliness by fingers	*Firmness*	*Graininess*	*Hardness by cutting*	*Hardness on first bite*	*Springiness*
True Strain at Yield	^{ns}–0.53	*–0.77	^{ns}–0.43	**–0.68	**–0.62	*0.76
True Stress at Yield	**0.59	*0.74	**0.60	**0.62	**0.65	*–0.72
True Strain at Fracture	*–0.76	*–0.84	***–0.55	*–0.78	**–0.63	*0.87
True Stress at Fracture	^{ns}0.43	**0.64	^{ns}0.38	**0.70	**0.66	***–0.57
Work to Fracture	*–0.75	*–0.76	***–0.53	**–0.69	***–0.54	*0.83
True Youngs Modulus	***0.50	*0.74	***0.55	***0.57	**0.60	*–0.73

ns : not significant. ****P* = 0.05; ***P* = 0.01; **P* = 0.001.
ns : non significatif. ***p = *0,05* ; **p = *0,01* ; *p = *0,001.*

None of the rheological or chemical variables showed a significant correlation with the sensory parameter crumbliness by chewing.

These findings provided a firm basis to analyse the data further in an attempt to develop models for predicting the textural characteristics of Cheddar using multiple linear regression analysis.

The statistical models determined by the multiple regression analysis are listed in table VIII, together with the associated regression coefficients and the standard errors for the mean predicted values.

When the predicted values suggested by these models were compared to the actual sensory scores the standard errors for the mean predicted values were small for the majority of the attributes (table VIII). Figure 2 illustrates the relationship between the actual and predicted values for the sensory attribute firmness.

An accurate model for predicting crumbliness by fingers could not be constructed using the chemical or rheological parameters measured in this study.

No accurate model for predicting creaminess could be calculated using the Instron

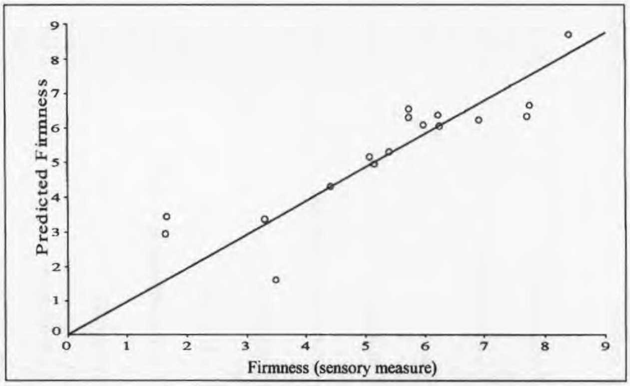


Fig 2. Predicted values vs sensory measures of firmness.
Relation entre les mesures sensorielles et instrumentales (prédites) de la fermeté.

Table VIII. Variables included in regression equations, r^2 and standard errors for each sensory attribute.
Variables utilisées dans les équations de régression, r^2 et écarts types des différents paramètres sensoriels.

Sensory attribute	*Springiness*	*Firmness*	*Log crumbliness by fingers*	*Hardness by cutting*	*Log creaminess*	*Hardness on first bite*	*Graininess*	*Crumbliness by chewing*
Variables included in equation	Log True Strain at Fracture	True Strain at Fracture True Stress at Yield	Log True Strain at Fracture [a]Log True Strain at Yield	True Strain at Fracture [a]Work to Fracture	Log% Fat [a]Log% Moisture	Log True Stress at Yield [a]True Stress at Fracture [a]True Strain at Yield	Log True Strain at Fracture [a]True Stress at Yield	Log Work to Fracture [a]Log True Strain at Fracture
Regression equation	7.85+(7.57 × Log True Strain at Fracture)	4.24+(-5.96 × True Strain at Fracture) + (51.99 × True Stress at Yield)	0.26+(-1.08 × Log True Strain at Fracture) +(0.29 × Log True Strain at Yield)	6.1+(-12.33 × True Strain at Fracture) +(15.28 × Work to Fracture)	-6.41+(2.3 × Log%Moisture) +(2.25 × Log% Fat)	13.61+(7.03 × True Stress at Fracture) +(6.93 × Log True Stress at Yield)+ (-17.08 × True Strain at Yield)	0.265+(-4.1 × Log True Strain at Fracture) + (25.91 × True Stress at Yield)	0.41+(-1.48 × Log True Strain at Fracture) + (-3.14 × Log Work to Fracture)
r^2	0.9	0.78	0.77	0.69	0.59	0.56	0.53	0.33
Standard error of mean predicted value	0.21	0.16	0.01	0.11	0.02	0.15	0.22	0.23

[a] Variable forced into regression equation.

variables but a fairly accurate model ($r^2 = 0.59$) was constructed using the logarithmic transformations of the percentage moisture and percentage fat content variables.

DISCUSSION

The results of this study revealed that the chemical indices measured have a very limited value in predicting the texture attributes perceived by the panel. It is widely accepted that the chemical composition of cheese effects its texture, however, Jack et al (1993) also found no correlations between compositional data and sensory parameters when working with Cheddar. The range of chemical composition in terms of the commercial samples representing one cheese type investigated in this study is comparatively small.

Chen et al (1979) and Casiraghi et al (1989) described relationships between the textural attributes of a range of different cheeses and their chemical composition but the samples exhibited a much larger compositional range. Similarly other researchers have found relationships between the composition and textural attributes of Cheddar (Marshall, 1990) but the samples investigated were outside the range of composition found in Cheddar available for retail sale. In addition it should be noted that changes in one chemical parameter have significant effects on others. The range of samples used for this investigation meant that no chemical parameter could be investigated in isolation which, as highlighted by Visser (1991), makes it difficult to isolate the relationship of any one chemical parameter with the textural attributes.

The only attribute to show any correlation with the chemical composition of Cheddar was creaminess. However it was also revealed that creaminess was one of the only two perceived attributes which could not be predicted by the rheological measures.

Accurate models were constructed using the Instron variables to predict all the remaining textural attributes apart from crumbliness by chewing ($r^2 = 0.52–0.9$).

It would be logical to expect a strong correlation between the sensory measure of springiness and Young's Modulus. However, although a significant relationship did exist ($r = -0.73$) a stronger relationship was identified with True Strain at Fracture — an observation also made by Green and Marshall (1985). This may suggest that the manner in which the panel perceive springiness is related to how much they are able to squeeze the sample in addition to the extent to which it springs back.

The True Strain at Fracture variable was included in several of the models constructed to predict the textural attributes. Green and Marshall (1985) also reported significant correlations between the 'compression at fracture' of Cheddar samples and panel measures of springiness, crumbliness and graininess. It was noted that as there were strong correlations between some of the textural attributes it was not as surprising that this rheological parameter correlated with more than one attribute. Combining additional variables with True Strain at Fracture in the regression equations enabled accurate models to be produced which included what appeared to be appropriate additional variables. For example the inclusion of the Work to Fracture variable in the model for predicting Hardness by cutting seems quite logical as the panel were measuring the amount of force required to penetrate the sample. Similarly the inclusion of the True Stress at Yield in the model to predict Firmness is also logical considering the fact that the panel were measuring the force required to compress the sample and so were probably only measuring firmness upto the point when the sample began to fail – the yield point.

It has been suggested that the relationships between instrumental and sensory parameters are not necessarily linear (Zoon, 1991). Indeed scatterplots of the parameters measured for this study revealed logarithmic relationships between several variables. For example the sensory measure of springiness appeared to increase more than the True Strain at Fracture variable. The logarithmic transformation of this variable resulted in a very significant correlation with the sensory measure of springiness ($r = 0.95$).

Closer observations of the accuracy of the suggested models and the manner in which the assessors tested for the associated attributes was also revealing. The most accurate models were produced for firmness, crumbliness by fingers, hardness by cutting and springiness. All of these attributes were tested, not by the palate but, either by squeezing between the fingers or with a knife.

The models produced for graininess and hardness on first bite were less accurate and interestingly were tested for using the mouth by the assessors. No accurate model could be produced for either creaminess or crumbliness during chewing using the Instron variables — attributes which were measured by the panel using a chewing action. These findings concur with the observation made by various researchers (Szscesniak, 1987) that more accurate models can be produced using instrumental variables when the test method used is similar to that used by the human assessors.

CONCLUSIONS

Compositional analyses are used routinely in cheese manufacture as part of the quality control system. Nevertheless this investigation found very limited correlation between the chemical measures and those textural attributes perceived by a trained panel. The exception was for creaminess where an accurate model was suggested using the fat and moisture content variables.

The use of the multiple regression technique enabled accurate models to be constructed that could predict the remaining textural attributes (apart from crumbliness by chewing), using the true rheological properties measured using the Instron Universal Testing Machine. Models were the most accurate for those attributes measured by the assessors using the fingers rather than the palate. Nevertheless all the models suggested, except that for crumbliness by chewing, offered an acceptable degree of accuracy.

The instrumental measurement of the true rheological properties of Cheddar cheese could be carried out easily and routinely in a Cheddar plant and therefore such methods offer a more cost effective approach to the measurement of the textural attributes when compared to sensory options.

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