Lait 81 (2001) 487–507

Original article

Relationships between the sensory characteristics, neutral volatile composition and gross composition of ten cheese varieties

J. Ben LAWLOR[a], Conor M. DELAHUNTY[a]*, Martin G. WILKINSON[b], Jeremiah SHEEHAN[b]

[a] Department of Food Science and Technology, Nutritional Sciences, University College, Cork, Ireland
[b] Dairy Products Research Centre, Moorepark, Fermoy, Co. Cork, Ireland

(Received 6 November 2000; accepted 9 January 2001)

Abstract — Relationships between the odour, flavour and texture sensory attributes and the neutral volatile composition and gross composition of ten varieties of cheese were determined. Sensory evaluation was carried out by fifteen trained assessors who used a vocabulary of nine odour, twenty-one flavour and ten texture terms. Volatile compounds were isolated in a bench top purge and trap model system, trapped on Tenax-TA and analysed using gas chromatography coupled with mass spectrometry. Gross composition was measured using standard methods. Results of Principal Components Analysis on the sensory data showed that the first seven Principal Components significantly discriminated between cheeses and accounted for 86% of the variation. Partial Least Squares regression was used to determine the relationship between significant sensory attributes and thirty identified volatile compounds and the gross compositional data. Six odour and eleven flavour attributes were positively correlated with subsets of volatile compounds and gross compositional data. Seven texture attributes were shown to be correlated to subsets of gross compositional measurements. Overall, the present study illustrated that individual cheese flavour and texture attributes are the result of complex interactions of specific volatile compounds and compositional variables.

sensory attribute / neutral volatile composition / gross composition / cheese / Partial Least Squares regression

Résumé — **Corrélation entre les caractéristiques sensorielles, la fraction volatile neutre et les principaux paramètres de composition de dix variétés de fromages.** Les caractéristiques sensorielles concernant l'odeur, le goût et la texture de dix variétés de fromages ont été corrélées à la composition de leurs fractions volatiles neutres et à leurs principaux paramètres de composition. Une

* Correspondence and reprints
Tel.: 353 902496; fax: 353 270244; e-mail: c.delahunty@ucc.ie

évaluation sensorielle a été réalisée par quinze sujets entraînés avec un vocabulaire de neuf descripteurs pour l'odeur, vingt et un pour le goût et dix pour la texture. Les composés volatils ont été isolés à l'aide d'un système de concentration des effluves sur polymère Tenax-TA et ont ensuite été analysés par chromatographie en phase gazeuse couplée à la spectrométrie de masse. Les principaux paramètres de composition ont été déterminés à l'aide de méthodes standards. Les analyses en composantes principales des données sensorielles ont montré que les sept premières composantes principales significativement discriminantes comptaient pour 86 % de la variation totale. Une méthode statistique de régression multidimensionnelle a été utilisée pour déterminer les corrélations entre les données sensorielles, trente composés volatils des différents fromages et leur composition. Six descripteurs d'odeur et onze de goût ont été positivement corrélés avec des groupes de composés d'arômes et certains paramètres de composition. Sept descripteurs concernant la texture ont été corrélés à des paramètres de composition. Cette étude a montré que l'arôme et la texture d'un fromage résultent d'interactions complexes entre la fraction volatile et les principaux paramètres de composition.

caractéristique sensorielle / fraction volatile neutre / composition / fromage / régression type PLS

1. INTRODUCTION

Increasing demand for non-Cheddar varieties of cheese is predicted as a growing number of consumers seek new flavour and texture varieties. However, although the importance of cheese flavour and texture to consumer preference has been shown [26, 35], there still exists inadequate scientific understanding of the specific contribution of cheese composition to flavour and texture development, and to individual flavour and texture perceptions in cheese when it is consumed.

Differing cheese manufacturing practices result in differences in gross composition, volatile composition, and ultimately differences in flavour and texture between cheese varieties. For example, fat content, which can now be standardised by the cheesemaker, plays an important role in the perceived flavour and texture of cheese. The breakdown of fat in the cheese matrix, by lipolysis, results in the liberation of free fatty acids (FFA's). FFA's, and their catabolites such as alkan-2-ones (2-methyl ketones), can act as important sources of flavour in mould-ripened cheeses [38], Italian hard cheeses and Swiss-type cheeses [25]. Fat also dissolves and absorbs most organic flavour compounds, influencing their release during consumption and subsequent contribution to perception. Finally, fat content plays a significant role in mouth feel, or texture, of cheese, and this is apparent in the texture differences between normal and reduced fat cheeses. Other compositional variables, such as the Salt-in-Moisture (S/M), Moisture-in the Non-Fat-Substances (MNFS) and Fat in Dry Matter (FDM) also influence cheese flavour and texture. For example, variations in S/M levels have been shown to have a marked effect on the rate of proteolysis in cheese [24, 27]. Such differences, in turn, may lead to differing rates of curd softening (due to casein breakdown) and variation in the rates of formation of flavour components derived from the catabolism of free amino acids, such as aldehydes, alcohols and sulphur compounds between cheese types.

By relating information on flavour and texture perceptions of cheeses obtained from descriptive sensory analysis, to chemical and/or physical parameters of the same group of cheeses, one could identify what Moskowitz [39] called the "true" or "operative" stimuli for flavour and texture perception. Such information could be used to optimise product formulations and focus technology inputs to influence product quality.

For flavour, Vangtal and Hammond [43] correlated the flavour notes, evaluated by a flavour profile method, of fifteen Swiss-type cheeses to pH, moisture, fat and salt measurements. They found both positive and negative associations. For example, "fruity" flavour was positively correlated with pH and salt content, while "nutty" flavour was negatively correlated to the same compositional variables. Relationships between volatile composition and cheese flavour have been more difficult to determine by statistical correlation. Banks et al. [1], related measures of FFA's, methyl ketones, esters, lactones, terpenes and indicators of protein breakdown to sensory attributes of Cheddar cheese using Partial Least Squares (PLS) regression, but only found that "flavour intensity" and "acid flavour" were related to combinations of these. "Flavour intensity" was associated positively with the extent of protein breakdown and with the concentration of 2-pentadecanone, and negatively with 3-hydroxy-2-butanone, phytene A and phytadiene. However, they believed that these relationships showed flavour association rather than causality. Virgilli et al. [45], who also used PLS regression, related individual odour and taste attributes of Parmigiano-Reggiano cheese to volatile and non-volatile components. They showed that certain odour and flavour attributes were related to groups of volatile and non-volatile compounds. For example, "intense" odour correlated positively with esters, free fatty acids, hexadecanol and two branched aldehydes. This approach, where volatile and non-volatile data are taken together to enable understanding of flavour, appears to be most valid.

To our knowledge, few other studies have investigated the relationship between individual sensory attributes and both volatile composition and gross composition of cheese at the same time. Gross composition reflects free amino acid and peptide composition, and often reflects FFA's and volatile composition. In addition, gross composition determines the release of volatile compounds during consumption [32, 33]. Therefore it may be most appropriate to consider both of these measures together in attempts to understand flavour perception.

For texture, Chen et al. [8] found that "hardness", "cohesivness", "adhesiveness" and "chewiness" were closely correlated with composition and pH of eleven varied cheese types, ranging from Parmesan to processed cheese. Casiraghi et al. [7] found "chewiness" to be correlated with both total solids and protein, and "hardness" to be correlated with total solids for a range of Italian cheeses. Hort et al. [16] investigated the relationship between six perceived textural characteristics of seventeen samples of Cheddar cheese, of different age and origin, and their chemical and rheological data. It was found that the rheological data was much better than compositional data in relation to sensory texture. However, authors did acknowledge that the limited range of cheeses, covering only a small range of compositional contents, could have limited the study. Most recently, Noël et al. [40] investigated relationships between sensory data and rheological, proteolysis and gross composition, using ten different samples of two very different cheese types, namely, Appenzeller and Parmigiano-Reggiano. These workers not only found significant relationships between gross composition and sensory texture properties, but also, by using PLS regression, were able to predict some of the texture characteristics quite well and recommended this approach for similar investigations.

The aim of the present study was, firstly to investigate the relationship between gross composition and neutral volatile composition, and the odour and flavour sensory attributes of ten cheeses of very different type. Secondly, to determine relationships between gross composition and the texture attributes of these cheeses. By determination of these relationships, it was hoped to provide a broad understanding of the compositional differences between cheeses, and of how these differences are reflected in specific sensory attributes.

2. MATERIALS AND METHODS

2.1. Samples

Ten cheeses (Tab. I), chosen to represent a range of flavour and texture types, were purchased from a local delicatessen (Horgan's delicatessen, Mitchelstown, Co Cork, Ireland). Samples for descriptive sensory analysis were stored at 4 °C prior to evaluation. Samples for analysis of volatile composition were vacuum packed, using a Webomatic type D-463 (Webomatic Vacuum Packaging Systems, Werner Bonk, Mausegatt 59, D-463 Bochum 6, Germany), and stored at –20 °C prior to analysis. The vacuum packaging material consisted of Cryovac (W. R. Grace Europe Inc., Av. Montchoisi 35, 1001 Lausanne, Switzerland) (45 $cm^3/m^2/24$ h at STP). Samples for analysis of gross composition were stored at 4 °C prior to duplicate evaluation.

2.2. Materials

All authentic standards used for identification of volatile compounds were "AnalaR" grade obtained from BDH Chemicals Ltd., Broom road, Poole, Dorset, UK; Sigma-Aldrich Ireland Ltd., Airlon Road, Tallagh, Dublin 24, Ireland; Merck Chemical Co. Ltd., D-6100, Darmstadt, Germany and Lancaster Synthesis Ltd. Eastgate, White Lund, Moorecambles, Lancashire, LA3 3DY, UK. Tenax TA (60/80) was purchased from Sigma-Aldrich Ireland Ltd. α-Amylase (from porcine pancreas) was purchased from Merck Chemical Co. Ltd.

2.3. Descriptive sensory analysis

A panel of 15 trained assessors (11 female, 4 male, aged between 20 and 30 years) described the sensory character of the cheeses. Prior to analysis assessors attended a number of group discussions during which the current list of descriptive attributes were developed [26]. Descriptive sensory analysis was carried out using a vocabulary of 9 odour, 21 flavour and 10 tex-

Table I. Cheeses investigated.

Code	Cheese	Cheese type	Origin
1	Mahón	lipolysed aromatic cheese	Spain
2	Cambozola	soft/semi-hard mould cheese	Germany
3	Gruyère	sweet cheese with eyes	Switzerland
4	Wensleydale	high acid crumbly type	UK
5	Blue Shropshire	soft/semi-hard mould cheese	UK
6	Tetilla	high fat and high acid	Spain
7	Ambassedeur	aromatic semi-hard	The Netherlands
8	Fontina	high fat and high acid	Italy
9	Appenzeller	semi-hard smear ripened	Switzerland
10	Chaumes	soft smear ripened	France

Table II. List of descriptive terms used by trained assessors to characterise cheeses.

Odour attributes		
pungent	sweaty/sour	dairy sweet
caramel	fruity	sweet
silage	mouldy	creamy
Flavour attributes		
buttery	nutty	acidic
caramel	smoky	bitter
dairy sweet	soapy	pepper
rancid	silage	burnt after-taste
mushroom	processed	astringent
oily	sweet	strength
mouldy	salty	balanced
Texture attributes		
firmness	moist	grainy
rubbery	oily	mouth-coating
crumbly	chewy	
smooth	slimy	

ture terms (Tab. II). On the morning of assessment the outer 5 mm of each cheese was removed and cheeses were cut into 5 g cubes. Each sample was equilibrated to room temperature (21 ^{o}C) and presented in a glass tumbler covered with a clock glass and coded with a randomly selected three-digit number. Each panellist was provided with water, non-salted crackers and tooth-picks to cleanse their palate between samples. Each panellist was also provided with a full list of definitions for each of the attributes. Cheeses were scored for attributes on unstructured 100 mm line scales anchored at both ends with extremes of each attribute. To account for first order and carry-over effects order of tasting for between and within days was balanced [34]. Data were recorded and stored using the PSA-system (Oliemans, Punter and Partners Inc. 3508 SG Utrecht, The Netherlands). All samples were analysed in duplicate.

2.4. Volatile composition

Prior to evaluation, samples were thawed from frozen at 4 ^{o}C overnight. The outer layer (2 cm) of each cheese was removed to minimise the possibility of compounds from the package, which might have migrated into the cheese sample, being mistaken for cheese compounds. The cheese was then grated and a 10 g sample transferred into a sample flask (100 mL) of a bench-top purge and trap system. Artificial saliva (15 mL) [44] was then added and the sample mixture, held at 37 ^{o}C in a water bath, was purged through with purified N_2 (100 mL·min^{-1}) for 30 min to trap volatiles on Tenax TA.

The Tenax-TA traps were thermally desorbed using a Tekmar 3000 concentrator (JVA Analytical Ltd. Unit 1, Longmile Business Centre, Longmile Road, Dublin

12, Ireland) for 6 min at 230 °C. Desorbed volatiles were identified and quantified using a Saturn GC-3400cx Gas Chromatograph-Saturn 3 Mass Spectrometer (GC-MS) (JVA Analytical). The GC column used was an Rtx-502.2, 60 m × 0.53 mm *id*, film thickness 3 µm (Interscience, Barrenscourt Lane, Belfast, 13T8 8RR, Northern Ireland). The GC oven was programmed from 40 °C (5 min), increased to 80 °C at 2 °C per min^{-1} (20 min), increased to 200 °C at 3 °C min^{-1} (40 min) and increased to 240 °C at 10 °C min^{-1} (4 min) to give a total run time of 69 min. All analyses were performed in duplicate.

2.5. Gross composition and pH

Gross composition was analysed using the following methods, moisture [17], protein [21], fat [19], salt [20], ash [18], calcium [18] and pH [5]. All analyses were performed in duplicate.

2.6. Data treatment

Descriptive sensory data was analysed as follows. Duplicate sample scores of assessors were averaged for each attribute and analysed using one-way analysis of variance (ANOVA) (SPSS v 6.1, SPSS Inc. Chicago, IL 60611, USA).

Descriptors which did not significantly discriminate between cheeses were removed from further analysis. Data were subsequently standardised (1/standard deviation) and analysed using Principle Components Analysis (PCA; [41]). PCA was carried out using Unscrambler v 6.1 (CAMO AS, N-7041 Trondheim, Norway). PCA is a bilinear modelling method that gives an interpretable overview of the main information in a multidimensional data matrix. The information carried by the original variables is projected onto a smaller number of underlying "latent" variables called Principal Components (PC's). How each PC discriminated between the sensory character of the cheeses was then investigated using one-way analysis of variance (ANOVA) (SPSS v 6.1).

Data on volatile composition were analysed in the following manner. Thirty compounds were chosen, none of which were detected in substantial quantities in blank analyses of the artificial saliva. The peak area of each compound was determined either by total ion, or in the case of overlapping peaks, by single ion plots. Compounds were identified by comparison to retention times and mass spectra of authentic standards and with comparison with bibliographic data (NIST92). The log peak area of each compound was calculated and data were then standardised (1/standard deviation) and analysed by PCA. How each PC discriminated between the volatile composition of the cheeses was then investigated using one-way ANOVA (SPSS v 6.1, SPSS Inc.).

Relationships between both volatile and gross compositional data, and the sensory attributes were investigated using Partial Least Squares (PLS) regression (PLS; [37]), using Unscrambler v 6.1 (CAMO AS). PLS regression is a bilinear modelling method where information in the original *X*-data is projected onto a small number of underlying ("latent") variables called PLS components. The *Y*-data are actively used in estimating the "latent" variables to ensure that the first components are those that are most relevant for predicting the *Y*-variables. Interpretation of the relationship between *X*-data and *Y*-data is then simplified as this relationship is concentrated on the smallest possible number of components. PLS1, which regresses one *Y*-(sensory) variable at a time, was used in the current study. Two separate analyses were performed. The first PLS analysis related both volatile compounds and gross composition (*X*-matrix) to individual odour and flavour attributes (*Y*-matrix). The second analysis related gross composition (*X*-matrix) to individual texture attributes (*Y*-matrix). For each analysis a plot of the regression coefficients of the PLS model illustrated the contribution of each of the *X*-variables (volatile compounds and/or compositional measurements) in predicting individual *Y*-variables (sensory attributes). *X*-variables with a small negative or positive coefficient that contributed little information were removed and the model was recalculated. Selection of the optimum model was based on the minimum value of the Root Mean Square Error of Prediction (RMSEP). This value, expressed in the same units as the *Y*-variable (i.e., on a scale of 1–100), shows the average uncertainty that can be expected when predicting *Y* (sensory) values for new samples. The strength of the model (calibration coefficient) and its ability to predict the sensory attributes of future samples (validation coefficient) were also tested using full cross validation.

3. RESULTS AND DISCUSSION

3.1. Descriptive sensory analysis

The attributes "dairy sweet" odour and "caramel", "dairy sweet", "smoky" and "soapy" flavour did not significantly ($P > 0.05$) distinguish between cheeses and were consequently not included in the PCA. The PCA, carried out on significant attributes, found that seven PC's, accounting for 86% of the experimental variance, significantly ($P < 0.05$) discriminated between cheeses. The scores and loadings of cheeses and descriptive sensory attributes on the first seven PC's, as well as the percentage variance accounted for by each PC, can be seen in Tables III and IV, respectively.

PC1 distinguished Wensleydale and Gruyère from Chaumes and Fontina. The former cheeses were characterised by a "caramel" odour and a "firmness" and

Table III. Results of PCA on the sensory attributes of ten cheese varieties showing the scores and the percentage variance (% var.) accounted for by the first seven PC's.

	Principal component						
Cheese	1	2	3	4	5	6	7
Mahón	2.05	2.54	–0.94	**–3.59**	1.24	**–1.63**	–0.67
Cambozola	–2.54	–0.91	**–4.17**	1.57	–0.57	0.01	0.93
Gruyère	**5.25**	–0.47	1.98	**3.76**	–1.04	–0.53	–0.86
Wensleydale	**5.61**	0.01	–1.13	**–2.43**	–1.44	1.77	0.68
Blue Shropshire	–2.27	**5.03**	**–2.21**	1.70	–0.62	0.16	–0.75
Tetilla	1.49	**–4.05**	–1.92	0.99	**2.71**	–0.42	0.16
Ambassedeur	–1.45	–2.14	**2.25**	–1.10	**–1.48**	–0.98	0.06
Fontina	**–2.76**	–0.58	1.89	–0.40	1.70	**2.00**	**–1.22**
Appenzeller	–0.94	2.93	**3.56**	0.76	1.24	–0.08	**1.88**
Chaumes	**–4.44**	–2.35	0.69	–1.26	**–1.75**	–0.29	–0.22
% var.	25	16	15	15	8	4	3

The most important scores on each PC are in bold.

Table IV. Results of PCA on the sensory attributes of ten cheese varieties showing the loadings on the first seven PC's.

Attribute	Principal component						
Odour	1	2	3	4	5	6	7
Pungent	**–0.24**	0.10	0.14	–0.10	–0.04	–0.07	–0.17
Caramel	**0.25**	–0.03	–0.09	–0.06	–0.10	**0.34**	0.02
Sweaty	–0.17	0.02	0.14	**–0.27**	**–0.24**	**–0.20**	–0.02
Sweet	0.08	0.03	0.15	**0.33**	**0.25**	**0.27**	–0.02
Creamy	0.12	**–0.20**	**–0.25**	0.02	0.03	0.17	**0.25**
Fruity	0.12	0.10	0.08	**0.37**	0.01	–0.04	–0.18
Mouldy	–0.13	0.16	**–0.26**	0.16	–0.15	0.07	–0.05
Silage	–0.17	0.04	**0.25**	–0.04	0.16	**0.37**	–0.10
Flavour							
Buttery	0.02	–0.17	**–0.24**	0.09	**0.36**	–0.16	0.07
Rancid	**–0.26**	0.08	0.09	–0.03	–0.13	0.06	–0.12
Mushroom	**–0.21**	0.14	–0.05	0.17	**–0.21**	–0.14	0.15
Oily	**–0.25**	–0.16	–0.04	–0.05	–0.06	0.10	0.01
Mouldy	–0.14	0.15	**–0.26**	0.17	–0.14	0.10	–0.03
Nutty	0.00	0.10	0.19	**0.36**	–0.17	–0.10	0.02
Silage	–0.16	0.02	**0.20**	–0.01	0.16	**0.46**	**–0.22**
Processed	–0.10	**–0.27**	0.10	–0.10	0.19	0.14	–0.02
Sweet	0.13	0.05	0.05	**0.38**	–0.06	–0.02	**–0.27**
Salty	–0.02	**0.24**	–0.14	–0.19	**0.21**	–0.18	–0.19
Acidic	0.06	**0.31**	0.05	–0.16	0.16	–0.08	0.11
Bitter	–0.14	0.09	**–0.21**	–0.11	**0.21**	0.13	**–0.25**
Pepper	–0.06	0.16	**0.23**	0.10	0.17	0.04	**0.60**
Burnt aftertaste	**–0.22**	0.14	0.11	0.15	–0.03	0.11	**0.23**
Astringent	0.00	**0.31**	0.11	–0.10	0.10	0.10	**0.29**
Strength	–0.15	**0.29**	0.08	0.06	–0.03	–0.01	–0.13
Balanced	0.11	**–0.27**	0.02	**0.23**	–0.01	0.01	–0.04
Texture							
Firmness	**0.26**	0.06	0.15	0.04	0.03	–0.08	–0.05
Rubbery	–0.05	**–0.24**	**0.26**	0.02	0.01	–0.12	–0.06
Crumbly	0.19	0.16	–0.12	–0.18	–0.16	0.19	–0.09
Smooth	**–0.25**	–0.12	–0.06	0.13	0.13	–0.05	0.05
Moist	**–0.25**	–0.10	–0.14	0.07	0.05	–0.08	0.12
Oily	**–0.25**	–0.16	–0.05	–0.01	–0.04	0.06	–0.02
Chewy	0.05	–0.08	**0.36**	–0.07	–0.19	–0.13	–0.07
Slimy	**–0.23**	–0.15	–0.12	0.03	–0.11	0.08	0.09
Grainy	**0.21**	0.14	–0.10	–0.12	**–0.21**	**0.26**	0.09
Mouth-coating	–0.03	**0.21**	–0.07	0.05	**0.45**	**–0.20**	–0.13

The most important loadings on each PC are in bold.

"grainy" texture. Both Chaumes and Fontina on the other hand were described as having a "pungent" odour, a "rancid", "oily" and "burnt after-taste" flavour and a "smooth", "moist", "oily" and "slimy" texture (Tabs. III and IV). PC2 distinguished Blue Shropshire from Tetilla cheese. Blue Shropshire was described by assessors as having a "salty", "acidic", "astringent" and "strength" flavour and a "mouth-coating" texture. Tetilla cheese, on the other hand, was characterised by a "creamy" odour, and a "processed" and "balanced" flavour. Successive PC's highlighted other differences in sensory character between cheeses. For example, PC3 distinguished between the "creamy", "mouldy" odour and "buttery", "mouldy", and "bitter" flavour of Cambozola and Blue Shropshire and the "pepper" flavour "rubbery" and "chewy" texture of Appenzeller and Ambassedeur cheeses.

3.2. Volatile composition

The volatile compounds identified in the present study (Tab. V) were as follows: two alcohols; four aldehydes; one anisole; ten esters; eight ketones; two sulphur compounds and three terpenes. Coefficients of variation ranged from 0.22 to 36.76%, however, due to space limitations these data are not shown. Due to the diverse nature of the cheeses, most compounds were not found in all cheeses, however the data are shown as log transformed peak areas in Table V. PCA of this data found that the first six PC's discriminated significantly ($P < 0.05$) between cheeses, and accounted for 76% of experimental variance. The scores and loadings of cheeses as well as the percentage variance accounted for by each PC, are presented in Tables VI and VII, respectively. In the following explanation of cheese composition, the discrimination observed on each PC will be interpreted in relation to the raw data shown in Table V.

PC 1 separated Blue Shropshire from all other cheeses (Tab. VI). In fact, Blue Shropshire was a considerable outlier on this PC as it contained nine compounds not found in any of the other cheeses (Tab. V). The four ester compounds with negative loadings on this PC were all found exclusively in Blue Shropshire cheese (Tab. V). Ester compounds result from esterification reactions between fatty acids and alcohols. Hydrolysis of milk fat to fatty acids is essential for flavour in blue cheeses and is particularly extensive in blue cheeses due to the lipase activity of the mould during ripening. Fatty acids can also act as important precursors of 2-methyl ketones. Blue Shropshire cheese was also characterised by a high concentration of 2-methyl ketones, including, 2-pentanone, 2-hexanone, 2-octanone and 2-nonanone. The mould, e.g. *Penicillium roqueforti*, oxidises saturated fatty acids to β-ketoacids that are subsequently decarboxylated to methyl ketones. Gallois and Langlois [12] found that methyl ketones represented 50–75% of the total odorous profile of five French blue cheeses. Although not obvious by interpretation of the PCA result, it was found that the other blue mould cheese analysed in this study, Cambozola, contained relatively large quantity of 2-methyl ketones (Tab. V). However, the quantities of methyl ketones found were not near as those found in Blue Shropshire. The contribution of the straight-chain aldehydes, pentanal, hexanal and heptanal, to Tetilla and Fontina on this PC can also be seen in Table VII. Straight chain aldehydes are formed during β-oxidation of unsaturated fatty acids and their presence has been reported in Swiss cheese [22], Parmesan [6] and a number of European "appelation d'origine contrôlée" cheeses [4]. Engels et al. [11] reported relatively high concentrations of straight chain aldehydes in the water-soluble fraction of Gruyère and Parmesan cheeses that had a high occurrence of lipolysis.

Table V. Result of volatile compositional analysis of ten cheese varieties showing the log transformed peak areas of compounds. For identification of cheese codes refer to Table I.

	Cheese code									
Compounds and method of identification	1	2	3	4	5	6	7	8	9	10
Alcohols										
3-methyl-1-butanol (MS, RT)	4.9	0.00	4.11	4.83	6.35	4.77	0.00	5.14	0.00	5.18
3-hexen-2, 5-diol (MS)	0.00	0.00	0.00	0.00	0.00	3.54	0.00	0.00	0.00	0.00
Aldehydes										
butanal (MS, RT)	4.5	0.00	0.00	3.47	4.36	5.96	4.2	6.84	0.00	0.00
pentanal (MS, RT)	4.52	4.35	4.54	4.4	0.00	4.34	3.95	3.84	3.59	0.00
hexanal (MS, RT)	4.15	3.85	4.07	3.68	0.00	3.84	3.34	3.75	0.00	3.00
heptanal (MS, RT)	3.92	4.08	3.76	0.00	0.00	3.77	3.79	3.8	3.28	3.29
Anisoles										
4-methyl anisole (MS)	0.00	0.00	0.00	0.00	4.8	0.00	0.00	0.00	0.00	0.00
Esters										
ethyl acetate (MS, RT)	4.5	0.00	4.58	4.41	0.00	4.49	0.00	0.00	3.9	0.00
propyl acetate (MS, RT)	0.00	0.00	0.00	0.00	0.00	3.74	0.00	5.15	3.68	0.00
methyl butyrate (MS, RT)	0.00	0.00	0.00	0.00	5.38	0.00	0.00	0.00	0.00	0.00
ethyl butyrate (MS, RT)	5.92	0.00	5.81	5.28	0.00	5.69	0.00	5.67	5.29	0.00
2-methyl ethyl butyrate (MS)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.79	0.00	0.00
propyl butyrate (MS, RT)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.01	0.00	0.00
methyl hexanoate (MS)	0.00	0.00	0.00	0.00	5.72	0.00	0.00	0.00	0.00	0.00
ethyl hexanoate (MS, RT)	5.12	0.00	0.00	0.00	0.00	0.00	0.00	5.01	4.61	0.00
1-methylbutyl 2-methylpropanoate (MS)	0.00	0.00	0.00	0.00	5.58	0.00	0.00	0.00	0.00	0.00
3-methylbutyl butyrate (MS)	0.00	0.00	0.00	0.00	5.34	0.00	0.00	0.00	0.00	0.00
Ketones										
2-butanone (MS, RT)	6.44	5.5	5.17	5.62	6.27	6.39	6.74	6.33	0.00	6.38
2-pentanone (MS, RT)	6.15	6.05	4.68	4.29	7.77	4.18	4.95	4.28	4.40	5.48
2-hexanone (MS, RT)	0.00	5.54	0.00	0.00	7.55	0.00	0.00	0.00	0.00	0.00
5-hepten-2-one (MS)	0.00	0.00	0.00	0.00	4.77	0.00	0.00	0.00	0.00	0.00
2-heptanone (MS, RT)	6.79	7.22	6.54	5.26	7.66	5.61	5.54	0.00	4.31	5.63
5-methyl-2-heptanone (MS)	0.00	0.00	0.00	0.00	4.45	0.00	0.00	0.00	0.00	0.00
2-octanone (MS, RT)	0.00	0.00	0.00	0.00	5.57	0.00	0.00	0.00	0.00	0.00
2-nonanone (MS, RT)	0.00	0.00	0.00	0.00	4.71	0.00	0.00	0.00	0.00	0.00
Sulphur compounds										
dimethyl disulphide (MS, RT)	4.52	5.79	5.13	4.23	6.29	4.4	7.19	6.74	5.72	4.88
dimethyl trisulphide (MS)	0.00	2.9	3.34	0.00	4.98	3.28	0.00	4.85	3.43	0.00
Terpenes										
α-pinene (MS, RT)	5.8	4.82	4.26	3.59	5.11	4.41	3.8	4.63	3.76	3.75
α-phellandrene (MS)	0.00	0.00	0.00	0.00	0.00	0.00	5.01	0.00	0.00	0.00
Limonene (MS, RT)	5.23	3.78	3.35	3.61	3.91	4.75	4.7	3.57	3.16	3.17

RT = retention time, MS = mass spectra.

Table VI. Results of PCA on the volatile composition of ten cheese varieties showing the scores and the percentage variance (% var.) accounted for by the first six PC's.

	Principal component					
Cheese	1	2	3	4	5	6
Mahón	1.18	0.57	**2.83**	0.97	**1.47**	**–1.84**
Cambozola	0.11	**1.60**	–1.37	0.81	1.07	–1.36
Gruyère	1.36	0.97	0.35	–1.14	–0.24	–0.54
Wensleydale	1.26	1.16	1.03	–1.11	**–1.93**	0.51
Blue Shropshire	**–10.10**	–0.63	0.32	–0.20	0.08	0.24
Tetilla	**1.71**	–0.40	**2.92**	–0.07	0.27	**2.11**
Ambassedeur	0.97	1.43	**–2.02**	**3.13**	0.65	**1.76**
Fontina	**1.78**	**–5.73**	–0.71	1.08	–0.70	–0.58
Appenzeller	1.48	–0.61	**–2.10**	**–3.48**	**1.70**	0.53
Chaumes	0.26	**1.63**	–1.25	0.01	**–2.37**	–0.83
% var.	36	12	8	9	5	6

The most important scores on each PC are in bold.

PC2 separated Chaumes and Cambozola from Fontina. The 2-methyl ketone, 2-heptanone, that characterised Chaumes and Cambozola on this PC was also found in all other cheeses apart from Fontina. Fontina cheese was characterised by butanal, dimethyl trisulphide and five ester compounds, namely, ethyl butyrate, ethyl hexanoate, propyl acetate, propyl butyrate and 2-methyl ethyl butyrate. The high occurrence of ester compounds in Fontina cheese, an Italian high fat/high acid-type cheese, may be accounted for by the fact that Italian cheeses are made from rennet pasts containing pregastric esterases which cause extensive lipolysis [36]. PC3 separated Mahón and Tetilla from Ambassedeur and Appenzeller. Mahón and Tetilla cheeses, both Spanish cheeses, were characterised on this PC by the following compounds: the alcohols 3-methyl-1-butanol and 3-hexen-2, 5-diol (in Tetilla); the aldehydes butanal and hexanal; the esters ethyl acetate and ethyl butyrate; the ketone 2-butanone and the two monoterpene compounds α-pinene and limonene. Ambassedeur and Appenzeller, on the other hand were characterised by the sulphur compound dimethyl disulphide and the monoterpene α-phellandrene (in Ambassedeur). Dimethyl disulphide and the other sulphur compound dimethyl trisulphide (important on PC2) result from the degradation of sulphur containing amino acids. These two sulphur compounds have been reported in aged Brie and Swiss cheeses [23, 46], Parmesan cheese [6], Fontina cheese [4] and a number of hard type cheeses [11]. Mariaca et al. [31] investigated the terpenoid content of forty-seven plants from lowland and highland pastures from which cheeses were made. Authors reported the presence of a diverse range of terpene compounds including limonene, α-pinene and α-phellandrene, in thirteen, nine and four different plant species, respectively. The occurrence of these three monoterpenoids in plants could explain their presence in the present cheeses. Terpene compounds have been identified in Gruyère [3], Parmesan [6], Cheddar [30], Swiss Emmental [22] and a number of hard-type cheeses [11].

Other PC's also separated cheeses based on their volatile composition. For example, PC4 separated Ambassedeur from Appenzeller. Ambassedeur cheese was characterised by butanal and hexanal,

Table VII. Result of PCA on the volatile composition of ten cheese varieties showing the compound loadings on the first six PC's.

	Principal component					
Compound	1	2	3	4	5	6
Alcohols						
3–methyl-1-butanol	–0.10	–0.13	**0.35**	–0.02	**–0.42**	–0.12
3–hexen-2, 5-diol	0.05	–0.03	**0.30**	–0.01	0.06	**0.45**
Aldehydes						
butanal	–0.03	**–0.27**	**0.27**	**0.27**	0.00	**0.27**
pentanal	**0.20**	–0.01	0.14	0.03	**0.30**	0.05
hexanal	**0.18**	0.05	**0.20**	**0.29**	–0.17	–0.16
heptanal	**0.18**	–0.03	–0.07	0.17	**0.30**	–0.14
Anisoles						
4-methyl-anisole	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
Esters						
ethyl acetate	0.11	0.08	**0.34**	**–0.31**	0.13	0.09
propyl acetate	0.09	**–0.37**	–0.01	–0.13	0.11	**0.23**
methyl butyrate	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
ethyl butyrate	0.15	–0.18	**0.29**	**–0.25**	0.08	0.00
2-methyl-ethyl butyrate	0.05	**–0.42**	–0.07	0.13	–0.14	–0.12
propyl butyrate	0.05	**–0.42**	–0.07	0.13	–0.14	–0.12
methyl hexanoate	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
ethyl hexanoate	0.08	**–0.28**	0.02	–0.09	**0.30**	**–0.28**
1-methylbutyl 2-methylpropanoate	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
3-methylbutyl butyrate	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
Ketones						
2-butanone	–0.05	0.01	**0.21**	**0.46**	**–0.29**	–0.05
2-pentanone	**–0.23**	0.10	0.02	0.12	0.13	**–0.30**
2-hexanone	**–0.23**	0.03	–0.06	0.04	0.14	–0.14
2-heptanone	–0.12	**0.37**	0.13	–0.01	0.16	–0.07
2-octanone	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
2-nonanone	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
5-hepten-2-one	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
5-methyl-2-heptanone	**–0.28**	–0.05	0.03	–0.02	0.02	0.05
Sulphur compounds						
dimethyl disulphide	–0.08	–0.17	**–0.37**	**0.25**	**0.19**	0.12
dimethyl trisulphide	–0.11	**–0.29**	–0.04	–0.17	**0.18**	0.05
Terpenes						
α-pinene	–0.10	–0.09	**0.28**	0.16	**0.34**	–0.41
α-phellandrene	0.03	0.10	**–0.21**	**0.36**	0.13	**0.38**
limonene	0.01	0.05	**0.32**	**0.34**	**0.33**	0.14

The most important loadings on each PC are in bold.

2-butanone, dimethyl disulphide, α-phellandrene and limonene. Appenzeller was distinguished on this PC by containing the two esters ethyl acetate and ethyl butyrate.

It should be noted that in the present work only one sample from each cheese variety was studied. Differences in volatile composition between cheeses, within a variety, may occur due to variations in starter organisms, milk composition and/or flora (see Grappin, [13]).

3.3. Gross composition of cheeses

The results of compositional analysis demonstrated that the present range of cheeses covered a wide range of values for each compositional variable (Tab. VIII).

Fat and Fat in the Dry Matter (FDM) contents ranged from 25 g·100 g^{-1} and 45.36, respectively, in Ambassedeur to 41.71 g·100 g^{-1} and 70.28, respectively, in Cambozola. Fat not only solves lipophilic flavour compounds produced from the hydrolysis of fats and proteins, but also, prevents the casein network of cheese from developing into a tough, rubbery matrix. Protein, which represents the continuous solid phase of cheese, ranged from 13.81 g·100 g^{-1} in Cambozola to a maximum of 29.08 g·100 g^{-1} in Mahón cheese. The pH of cheeses ranged from 4.73 (Wensleydale) to 6.92 (Blue Shropshire). pH is important for flavour as it influences growth of Non Starter Lactic Acid Bacteria (NSLAB) in Cheddar and Gouda, growth of *Propionibacterium* sp. in Swiss-type cheese, and the dissociation and odour activity of volatile compounds e.g. FFA [2]. pH is also important for cheese texture, as pH changes are directly related to calcium content and protein network [27, 43].

Salt and Salt-in-Moisture (S/M) levels ranged from 1.12 g·100 g^{-1} and 2.63, respectively in Wensleydale to 2.75 g·100 g^{-1} and 10.49, respectively in Mahón cheese. The important influence of salt on cheese has been reviewed by Guinee and Fox [14]. Kelly et al. [24] demonstrated that the S/M level of Cheddar-like cheese has a marked

Table VIII. Compositional analysis of ten cheese varieties.

	Compositional measurement									
Cheese	Moisture[a]	Protein[a]	Fat[a]	Salt[a]	Ash[a]	Ca[a]	MNFS	FDM	S/M	pH
Mahón	26.21	29.08	36.99	2.75	5.23	902.00	41.60	50.13	10.49	5.33
Cambozola	40.65	13.81	41.71	1.57	2.60	379.00	69.74	70.28	3.86	6.48
Gruyère	39.02	27.63	29.26	1.27	3.48	764.50	55.16	47.98	3.25	5.63
Wensleydale	42.36	21.33	33.39	1.12	2.44	511.50	63.58	57.92	2.63	4.73
Blue Shropshire	38.29	24.81	33.67	1.20	2.62	368.50	57.73	54.56	3.13	6.92
Tetilla	34.50	23.80	36.40	1.30	N/D	N/D	54.25	55.57	3.77	5.65
Ambassedeur	44.89	24.92	25.00	1.54	3.62	747.00	59.85	45.36	3.43	6.25
Fontina	36.80	26.63	30.04	2.31	4.01	679.00	52.60	47.53	6.28	6.29
Appenzeller	36.50	26.57	33.50	1.32	3.36	731.00	54.89	52.76	3.62	6.03
Chaumes	49.00	20.00	25.77	2.13	3.54	530.50	66.01	50.53	4.35	5.97

N/D = Not determined.
[a] values expressed as g·100 g^{-1}.

effect on the rate and extent of proteolysis. Moisture in the Non-Fat Substances (MNFS) ranged from 41.60 in Mahón to 69.74 in Cambozola cheese. MNFS is essentially the relative amounts of moisture and protein in the cheese and this value is more relevant than the percentage moisture since it is in the interface of moisture and casein that enzymic reaction responsible for ripening take place [28]. Calcium content ranged from 379 mg·100 g^{-1} in Cambozola to 902 mg·100 g^{-1} in Mahón (this was also the case for ash content). Calcium content of cheese is largely determined at the point at which the curd is drained from the whey and has an important role in texture development.

3.4. Relationship between odour and flavour attributes and volatile and gross composition

Six odour and eleven flavour attributes were correlated to subsets of both volatile compounds and compositional measurements (Tabs. IX and X). Calibration coefficients (strength of the current models) were all ≥ 0.68, while the validation coefficients (ability to predict new samples) were all ≥ 0.46. RMSEP values ranged from 1.43 to 7.26 (on a scale of 1–100) indicating that the current models all had good predictive power for the current set of cheeses. However, since each volatile compound was not detected in all of the cheeses, and because models were attribute based (rather than cheese based), some cheeses described by a particular characteristic may not contain all of the compounds identified in the model. Therefore to interpret attributes in any individual cheese, rather than in a broad cheese context, it would be best to refer also to Table V. However, despite this consideration, the models in the current work are valid and indeed have been validated by PLS itself.

The "mouldy" odour, found in particular in Blue Shropshire and Cambozola cheeses, was positively associated with fat, FDM and pH, 2-pentanone, 2-hexanone, 2-heptanone and 2-octanone, and negatively correlated with calcium content (Tab. IX). It has been known for some time that 2-methyl ketones are a dominant part of blue cheese flavour [12, 25], particularly 2-heptanone which has been described as possessing a "blue flavour" note [15]. The presence of these compounds can be attributed to the high degree of lipolysis, due to the action of the mould, e.g. *Penicillium roqueforti*, on the fat during the ripening of these two cheese types. Furthermore, the de-acidifying activity of the mould during ripening may account for the positive associations between pH and "mouldy" odour, while the high rate of acid production during the manufacture of blue cheese with resulting solubilisation of colloidal calcium phosphate and consequent low mineral content is reflected in the negative association between calcium content and this odour attribute. Of these two mould cheeses, Blue Shropshire had the higher peak areas for all four methyl ketones and was also scored higher than Cambozola for "mouldy" odour (raw panel data not shown). This may have been due to mould type, more prolific mould growth, or to the composition, or more specifically, the fat content of these two cheeses. In comparison to Cambozola, Blue Shropshire had the lower fat content (41.71 and 33.67 g·100 g^{-1}, respectively) and FDM (70.28 and 54.56, respectively) (Tab. VIII). This lower fat content may have resulted in a higher rate of release of 2-methyl ketones from Blue Shropshire, lowering flavour threshold concentrations needed in the cheese, and hence, this cheese being described as having a more "mouldy" odour. Furthermore, the lack of 2-octanone in Cambozola may also be due to it's higher fat content, and the higher hydrophobicity of 2-octanone when compared to the other methyl ketones, resulting in a reduced partitioning into the gas phase. Delahunty et al. [10] found that release of higher molecular weight methyl ketones was lower in full-fat cheese (35%

Table IX. Result of PLS1 analysis between the odour attributes (*Y*-matrix) and volatile composition and gross composition (*X*-matrix) of ten cheese varieties showing the relationship between the odour attributes and volatile composition and gross compositional measurements. The fit of the current model, calibration coefficient (Cal. Coef), its ability to predict, validation coefficient (Val. Coef.), and the Root Mean Error Square Error of prediction (RMSEP) are shown. The companion of this table showing results for flavour attributes can be seen as Table X.

Odour	Measurement	Positively correlated	Negatively correlated	Cal. Coef	Val. Coef.	RMSEP
pungent	volatile	ethyl hexanoate, propyl acetate, 2-pentanone, dimethyl disulfide	pentanal, hexanal, ethyl acetate, ethyl butyrate, 2-heptanone	0.95	0.88	6.52
	composition	salt, ash, S/M, Ph	fat, FDM			
caramel	volatile	pentanal, hexanal, 3-methyl-1-butanol	propyl acetate, heptanal	0.99	0.96	1.86
	composition		ash, pH			
fruity	volatile	ethyl acetate, dimethyl trisulfide		0.81	0.56	7.26
	composition	protein	salt			
mouldy	volatile	2-pentanone, 2-hexanone, 2-heptanone, 2-octanone, dimethyl trisulphide	ethyl acetate	0.99	0.99	4.05
	composition	fat, FDM, Ph	Ca			
sweet	volatile	ethyl acetate, ethyl butyrate, propyl acetate, propyl butyrate, dimethyl trisulphide	α-phellandrene	0.96	0.77	5.17
	composition	protein	salt, S/M			
creamy	volatile	pentanal, hexanal, 2-butanone	ethyl hexanoate, dimethyl disulphide	0.97	0.93	4.45
	composition	fat, FDM, MNFS	protein, ash, pH			

fat) in comparison to reduced and low fat (23 and 16% fat respectively) cheeses.

"Sweet" odour, that helped describe the Swiss-type cheese Gruyère, and to a lesser extent Appenzeller (see also Lawlor and Delahunty [26]), was positively associated with protein content and negatively correlated with salt and S/M contents. In Gruyère cheese, ethyl acetate, ethyl butyrate and dimethyl trisulphide were positively correlated with this attribute. In Appenzeller cheese, on the other hand, "sweet" odour was positively associated with ethyl acetate, ethyl butyrate, dimethyl trisulphide, and propyl acetate. Vangtal and Hammond [43] showed that "sweet" flavour Emmental cheeses was correlated with the production of short chain acids and

Table X. Result of PLS1 analysis between the flavour attributes (*Y*-matrix) and volatile composition and gross composition (*X*-matrix) of ten cheese varieties showing the relationship between the flavour attributes and volatile composition and gross compositional measurements. The fit of the current model, calibration coefficient (Cal. Coef), its ability to predict, validation coefficient (Val. Coef.), and the Root Mean Error Square Error of prediction (RMSEP) are shown. The companion of this table showing results for odour attributes can be seen as Table IX.

Flavour	Measurement	Positively correlated	Negatively correlated	Cal. Coef	Val. Coef.	RMSEP
mushroom	volatile	dimethyl disulphide, heptanal, 2-pentanone, 2-hexanone, 2-octanone	ethyl acetate, ethyl butyrate, 3-methyl-1-butanol, 2-butanone, butanal, pentanal, hexanal	0.99	0.98	1.43
	composition	pH				
mouldy	volatile	2-pentanone, 2-hexanone, dimethyl disulphide dimethyl trisulphide		0.99	0.98	4.89
	composition	fat, FDM, MNFS, pH	Ca			
nutty	volatile	dimethyl disulphide, dimethyl trisulphide, 2-octanone	butanal, hexanal, 2-butanone, limonene	0.77	0.57	5.56
	composition	pH	fat, ash, salt, S/M			
silage	volatile	ethyl hexanoate, propyl acetate, propyl butyrate, dimethyl disulphide	ethyl acetate, 2-heptanone	0.98	0.91	6.19
	composition	pH	fat			
processed	volatile	propyl acetate, propyl butyrate	methyl hexanoate, 2-pentanone, 2-hexanone, 2-heptanone, 2-octanone	0.68	0.46	5.43
	composition	moisture	fat			

Table X (Continued).

Flavour	Measurement	Positively correlated	Negatively correlated	Cal. Coef	Val. Coef.	RMSEP
salty	volatile	ethyl hexanoate, 2-pentanone		0.91	0.87	4.90
	composition	S/M	moisture			
acidic	volatile	2-methyl-ethyl butyrate, ethyl hexanoate	hexanal, heptanal	0.98	0.83	5.73
	composition	protein	MNFS, moisture			
pepper	volatile	ethyl hexanoate, propyl acetate	hexanal, 3-methyl-1-butanol, 2-butanone, limonene	0.99	0.96	4.52
	composition	protein				
burnt after-taste	volatile	dimethyl disulphide	ethyl acetate, pentanal, hexanal	0.91	0.83	4.89
	composition	pH				
strength	volatile	ethyl hexanoate, dimethyl disulphide, 2-pentanone, 3-hexen-2, 5-diol	pentanal, hexanal	0.99	0.92	5.67
	composition	pH				
balanced	volatile	hexanal, heptanal		0.96	0.92	4.50
	composition		S/M, salt			

low salt concentration (which favours the growth of *Propionibacterium* sp. a salt sensitive organism). The "sweet" odour character of both Swiss-type cheeses in the present work were associated with esters, compounds derived from lipolysis and also a low salt and S/M content. However, it should also be noted that fatty acid precursors of ester compounds may also be synthesised by the cheese microflora, or, result from the breakdown of amino acids (see McSweeney, [36]). The flavour attribute "salty", that characterised Mahón cheese, was positively associated with S/M, ethyl hexanoate and 2-pentanone and negatively associated with moisture content (Tab. X). This cheese had the highest S/M (10.49) of all cheeses investigated, therefore, it was not surprising that this cheese was described as having a "salty" flavour. The "silage" flavour that described Fontina cheese (see PC6, Tab. IV) was positively associated with pH, ethyl hexanoate, propyl acetate, propyl butyrate and dimethyl disulphide. It was negatively associated with fat content. As mentioned previously the manufacture of Italian hard cheeses involves the addition of rennet pastes containing pregastric esterase that produces strong fatty acid flavours. The resulting high rate of lipolysis in these cheeses (although not as high as in blue-mould cheeses) may account for the association between esters and the "silage" flavour of Fontina cheese.

Considered individually, families of compounds, such as esters and sulphur compounds etc., possess characteristic flavours. For example, esters in cheese have been described as having floral, fruity notes [38], while sulphur compounds are described by a strong garlic, very ripe cheese odour [9, 42]. However, when these compounds are mixed in the same cheese matrix their behaviour is quite different and may indeed result in the relationships observed in the present work. Bosset and Gauch [4], in their study on the volatile fractions of six different cheese types, concluded that cheese flavour seemed not to depend on any particular key component, but rather on a balance or a "weighted ratio" of a number of components acting together. Engels [11] came to similar conclusions. The present study demonstrated that individual odour and flavour attributes of cheese not only depend on interactions between specific volatile compounds, but also, on interactions between specific compositional variables. However, it must be stressed that the current models are "associative" rather than "causeative", and just because variables are related in a statistical sense does not imply a cause-and-effect situation. Clearly, more work is required to support these findings. Based on the results of this study and a previous study [26] this will involve analysing a smaller-subset of cheeses, namely, Swiss-type cheeses and blue mould cheeses. In addition, the volatile compounds of these cheeses will be isolated using a model mouth system that will include a mastication device, while the contribution of the Water Soluble Fraction (WSF) and Free Fatty Acids to flavour in these two cheese-types will also be determined. Both the WSF and FFA are known to contribute to cheese flavour [11, 36] and their absence from the current data set may account for certain flavour terms in the present work remaining unexplained.

3.5. Relationship between texture attributes and gross composition

Seven out of the original ten texture attributes were shown to be correlated to subsets of gross compositional measurements (Tab. XI). Calibration coefficients were all ≥ 0.77, validation coefficients were all ≥ 0.52 and the RMSEP's ranged from 2.7 to 13.6 (on a scale of 1–100) indicating that the current models had good predictive power.

The texture attribute "firmness" that described Gruyère, (raw data not shown), a

Table XI. Result of PLS1 analysis between the sensory attributes (*Y*-matrix) and gross composition (*X*-matrix) of ten cheese varieties showing the relationship between the sensory attributes and gross composition. The fit of the current model, calibration coefficient (Cal. Coef), its ability to predict, validation coefficient (Val. Coef.), and the Root Mean Error Square Error of prediction (RMSEP) are shown.

Texture	Positively correlated	Negatively correlated	Cal. Coef.	Val. Coef.	RMSEP
Firmness	protein, Ca,	S/M, salt, moisture, pH	0.92	0.69	12.81
Rubbery	Ca, ash	moisture, protein, fat, FDM, S/M	0.98	0.81	9.45
Moist	moisture, MNFS, ash, salt, pH	protein	0.89	0.60	11.88
Oily	moisture, salt, MNFS, pH	protein	0.77	0.52	13.61
Chewy	moisture, MNFS, protein, ash, Ca	fat, FDM, salt, S/M, pH	0.99	0.94	2.76
Slimy	salt	moisture, protein, MNFS, FDM, S/M	0.99	0.68	10.02
Mouth-coating	protein, fat, FDM, ash, S/M, pH	moisture, MNFS, Ca, salt	0.98	0.92	2.83

Swiss-type cheese, was positively associated with protein and calcium content and negatively associated with moisture content, salt content, S/M and pH (Tab. XI). During Swiss-type cheese manufacture, high cooking temperatures (50–53 °C) have the effect of inactivating most of the chymosin in the curd (the more thermostable plasmin is not as affected [29]. The result of this is a general decrease in the rate of proteolysis and hence firmer textured cheese is obtained. Furthermore, the concentration of calcium has a major effect on texture and the high calcium content (764.5 g·100 g^{-1}) of this cheese could help explain its "firmness". The high mineral content of the curd is achieved by a low percentage of starter and a high scalding temperature [29]. "Moist" texture, which characterised Cambozola cheese, a surface mould ripened cheese, was positively associated with moisture, salt and ash content, pH and MNFS and negatively associated with protein content. Cambozola had the highest MNFS of all cheeses studied (69.74) which is an indication of the relative amount of moisture to protein in the cheese. As protein represents the only continuous solid phase of the cheese this may explain why Cambozola cheese was described as possessing a "moist" texture. The attribute "oily" texture, describing Chaumes and Cambozola, was positively associated with moisture, MNFS, salt content and pH. Both Chaumes and Cambozola are classified as soft cheeses and both had the highest MNFS ratio and lowest protein contents. "Chewy" texture, characterising Ambassedeur cheese, was associated with most compositional variables, in particular calcium content (positive) and fat content and FDM (negative). Ambassedeur was also described as "rubbery" in texture; this attribute was also negatively associated with fat content and FDM and positively associated with calcium concentrations. Fat in cheese has the effect of preventing the protein (casein) network of the cheese matrix from shrinking into a tough inedible structure, while calcium confers a "firmness" to cheese texture, which explains why Ambassedeur was described as having a "chewy" and "rubbery" texture.

In conclusion, the relationships between odour, flavour and texture sensory characteristics and volatile composition and gross composition were determined. Results indicated that cheese flavour and texture are multi-dimensional phenomenon resulting from complex interactions between manufacturing method, volatile composition and the gross composition of cheese.

ACKNOWLEDGEMENTS

Authors would like to thank Dr. S. Hulin-Bertaud and Dr. M.A. Posthumus for their assistance. This work was funded by the Department of Agriculture, Food and Rural Development of Ireland, under the Non-Commissioned Food Research Programme 1994–2000

REFERENCES

[1] Banks J.M., Brechany E.Y., Christie W.W., Hunter E.A., Muir D.D., Volatile components in steam distillates of Cheddar cheese as indicator indices of cheese maturity, flavour and maturity, Food Res. Int. 25 (1992) 365–373.

[2] Bennett C.J., Formulating low-fat foods with good taste, Cereal Foods World 37 (1992) 429–432.

[3] Bosset J.O., Bütikofer U., Gauch R., Sieber R., Caractérisation de fromages d'alpages subalpins suisses : mise en évidence par GC-MS de terpènes et d'hydrocarbures aliphatiques lors de l'analyse par "Purge and Trap" des arômes volatils de ces fromages, Schweiz. Milchwirt. Forsch. 23 (1994) 37–41.

[4] Bosset J.O., Gauch R., Comparison of the volatile flavour compounds of six European "AOC" cheeses by using a new dynamic headspace GC-MS method, Int. Dairy J. 3 (1993) 359–377.

[5] BSI, British standard method for chemical analysis of cheese, part 5, determination of pH value, British standards institute, 2 Park St., London W1A 2BS, England, 1976.

[6] Careri M., Manini P., Spagnoli S., Barbieri G., Bolzoni L., Simultaneous distillation-extraction and dynamic headspace methods in gas chromatographic analysis of Parmesan cheese volatiles, Chromatographia 38 (1994) 386–394.

[7] Casiraghi E., Lucisano M., Pompei C., Correlation among instrumental texture, sensory texture and chemical composition of five Italian cheeses, Ital. J Food Sci. 1 (1989) 53–63.

[8] Chen A.H., Larkin J.W., Clark C.J., Irwin W.E., Texture analysis of cheese, J. Dairy Sci. 62 (1979) 901–907.

[9] Cuer A., Dauphin G., Kergomard A., Roger S., Dumont J.P., Adda J., Flavour properties of some sulfur compounds isolated from cheese, Lebensm. Wiss. Technol. 12 (1979) 258–261.

[10] Delahunty C.M., Piggott J.R., Conner J.M., Paterson A., Comparison of dynamic flavour release from hard cheeses and analysis of headspace volatiles from the mouth with flavour perception during consumption, J. Sci. Food Agric. 71 (1996) 273–271.

[11] Engels W.J.M., Dekker R., deJong C., Neeter R., Visser S.A., Comparative study of volatile compounds in the water-soluble fraction of various types of ripened cheese, Int. Dairy J. 7 (1997) 255–263.

[12] Gallois A., Langlois D., New results in the volatile odorous compounds of French cheeses, Lait 70 (1990) 89–106.

[13] Grappin R., Beuvier E., Bouton Y., Pochet S., Advances in the biochemistry and microbiology of Swiss-type cheeses, Lait 79 (1999) 3–22.

[14] Guinee T.P., Fox P.F., Salt in cheese: physical, chemical and biological aspects, in: Fox P.F. (Ed.), Cheese: chemistry, physics and microbiology, Chapman and Hall, London, 1997, pp. 257–302.

[15] Hall G., Anderson J., Volatile fat oxidation products. I. Determination of odour thresholds and intensity functions, Lebensm. Wiss. Technol. 16 (1983) 354–361.

[16] Hort J., Grys G. Woodman J., The relationship between the chemical, rheological and textural properties of Cheddar cheese, Lait 77 (1997) 587–600.

[17] IDF, Cheese and processed cheese: moisture determination, determination of the total solids content, Standard 4A, Int. Dairy Fed., Brussels, Belgium, 1982.

[18] IDF, Milk and dried milk: determination of calcium content, flame atomic absorption spectrometric method, standard 154, Int. Dairy Fed., Brussels, Belgium, 1984.

[19] IDF, Fat, Cheese and processed cheese: determination of fat content, Schmid-Bondzynski-ratzlaff method, Standard 5B, Int. Dairy Fed., Brussels, Belgium, 1986.

[20] IDF, Cheese and processed cheese: salt determination, determination of chloride content, potentiometric titration method, Standard 88A, Int. Dairy Fed., Brussels, Belgium, 1988.

[21] IDF, Protein determination, milk: determination of N content, Kjeldahl method, and calculation of crude protein content, Standard 20 B, Int. Dairy Fed., Brussels, Belgium, 1993.

[22] Imhof R., Bosset J.O., The performance of various capillary columns for the analysis of volatile flavour compounds in dairy products by dynamic headspace gas chromatography, J. High Res. Chromatogr. 7 (1994) 25–30.

[23] Karahadian C., Josephson D.B., Lindsay R.C., Volatile compounds from *Penicillium sp.* Contributing musty-earthy notes to Brie and Camembert cheese flavours, J. Agric. Food Chem. 33 (1985) 339–343.

[24] Kelly M., Fox P.F., McSweeney P.L.H., Effect of salt-in-moisture on proteolysis in Cheddar type cheese, Milchwissenschaft 51 (1996) 498–501.

[25] Law B.A., Flavour compounds in cheese, Perfum. Flavour. 7 (1982) 9–21.

[26] Lawlor J.B., Delahunty C.M., The sensory profile and consumer preference for ten speciality cheeses, Int. J. Dairy Technol. 53 (2000) 28–36.

[27] Lawrence R.C., Creamer L.K., Gilles J., Texture development during cheese ripening, J. Dairy Sci. 70 (1986) 1748–1760.

[28] Lawrence R.C., Gilles J., The assessment of the potential quality of young Cheddar cheese, N.Z.J. Dairy Sci. Technol. 15 (1980) 1–12.

[29] Lawrence R.C., Heap H.A., Gilles J., A controlled approach to cheese technology, J. Dairy Sci. 67 (1984) 1632–1645.

[30] Liebich H.M., Douglas D.R., Bayer E., Zlatkis A., The volatile components of Cheddar cheese, J. Chromatogr. Sci. 8 (1970) 355–359.

[31] Mariaca R.G., Berger T.F.H., Gauch R., Imhof M.I., Jeangros B., Bosset J.O., Occurrence of volatile mono– and sesquiterpenoids in highland and lowland plant species as possible precursors for flavour compounds in milk and dairy products, J. Agric. Food Chem. 45 (1997) 4423–4434.

[32] Matheis G., Interactions between volatile flavoring substances and food constituents. Part 1: Carbohydrates, proteins and amino acids, Dragco Report 3 (1993) 98–114.

[33] Matheis G., Interactions between volatile flavoring substances and food constituents. Part 2: Lipids, inorganic salts, fruit acids, purine alkaloids, phenolic compounds, ethanol and complex systems, Dragco Report 4 (1993) 148–159.

[34] MacFie H.J., Bratchell N., Greenhoff K., Vallis I.V., Designs to balance the effect of order of presentation and first-order carry-over effects in hall tests, J. Sens. Stud. 4 (1989) 129–148.

[35] McEwan J., Moore J.D., Colwill J.S., The sensory characteristics of Cheddar cheese and their relationship with acceptability, J. Soc. Dairy Technol. 4 (1989) 112–117.

[36] McSweeney P.L.H., Sousa M.J., Biochemical pathways for the production of flavour compounds in cheese during ripening: A review, Lait 80 (2000) 293–324.

[37] Martens M., Martens H., Partial least squares regression, in Piggott J.R. (Ed.), Statistical Procedures in Food Research, Elsevier Applied Science, London, 1986, pp. 293–359.

[38] Molimard P., Spinnler H.E., Compounds involved in the flavour of surface mold-ripened cheeses: Origins and Properties, J. Dairy Sci. 79 (1996) 169–184.

[39] Moskowitz H.R., Relating subjective and instrumental measures a psychophysical overview, J. Food Qual. 4 (1981) 15–33.

[40] Noël Y., Ardö Y., Pochet S., Hunter A., Lavanchy P., Luginbühl W., Le Bars D, Polychroniadou A., Pellegrino L., Characterisation of protected denomination of origin cheeses: relationships between sensory texture and instrumental data, Lait 78 (1998) 569–588.

[41] Piggott J.R., Sharman K., Methods to aid interpretation of multidimensional data, in: Piggott J.R. (Ed.), Statistical Procedures in Food Research, Elsevier Applied Science, London, 1986, pp. 181–232.

[42] Urbach G., The flavour of milk and dairy products: II. Cheese: contribution of volatile compounds, Int. J. Dairy Technol. 50 (1997) 79–89.

[43] Vangtal A., Hammond E.G., Correlation of the flavour characteristics of Swiss-Type cheeses with chemical parameters, J. Dairy Sci. 69 (1986) 2982–2993.

[44] van Ruth S.M., Roozen J.P., Cozijnsen J.L., Comparison of dynamic headspace mouth model systems for flavour release from rehydrated sliced bell peppers, in: Maarse H., van der Heij. (Eds.), Trends in Flavour Research, Elsevier, Amsterdam, The Netherlands, 1994, pp. 59–64.

[45] Virgili R., Parolari G., Bolzoni L., Barbieri G., Mangia A., Careri M., Spagnoli S., Panari G., Zannoni M., Sensory-Chemical relationships in Parmigiano-Reggiano cheese, Lebensm.-Wiss. Technol. 27 (1994) 491–495.

[46] Yang W.T., Min D.B., Dynamic headspace analysis of volatile compounds of Cheddar and Swiss cheese during ripening, J. Food Sci. 59 (1994) 1309–1312.