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Modelling of sensory and instrumental texture parameters in processed cheese by near infrared reflectance spectroscopy

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This study investigated the application of near infrared (NIR) reflectance spectroscopy to the measurement of texture (sensory and instrumental) in experimental processed cheese samples. Spectra (750 to 2498 nm) of cheeses were recorded after 2 and 4 weeks storage at 4 °C. Trained assessors evaluated 9 sensory properties, a texture profile analyser (TPA) was used to record 5 instrumental parameters and cheese 'meltability' was measured by computer vision. Predictive models for sensory and instrumental texture parameters were developed using partial least squares regression on raw or pre-treated spectral data. Sensory attributes and instrumental texture measurements were modelled with sufficient accuracy to recommend the use of NIR reflectance spectroscopy for routine quality assessment of processed cheese.

Keywords: Cheddar cheese, near infrared, texture, sensory analysis.

Food texture is important as a quality indicator that consumers use to accept or reject a food product (Guinard & Mazzucchelli, 1996); proper control of the parameters that describe texture would therefore enable the food processor to make products with the highest quality and consumer acceptability exhibiting a wide range of textures. Characterisation of cheese texture is traditionally carried out in two ways i.e. by (1) sensory and (2) instrumental methods. Both these approaches are time-consuming and the latter are somewhat empirical. Processed cheese is a complex system principally composed of protein, fat, minerals and water obtained by blending, mixing and heating natural cheeses of different maturity, emulsifying salts and water (Carić et al. 1985). Its texture is influenced by the chemical composition of the initial cheese and the processing conditions used during manufacture (Carić & Kaláb, 1993) as well as by the type and amount of emulsifier incorporated.

Near infrared spectroscopy is widely-used in the dairy industry for the determination of cheese constituents i.e. moisture and fat content (McQueen et al. 1995; Lee et al. 1997; Blazquez et al. 2004), inorganic salts (Blazquez et al. 2004), total solids (Rodriguez-Otero et al. 1997), protein content (Rodriguez-Otero et al. 1997; Lee et al. 1997) and dry matter (Wittrup & Norgaard, 1998; Picque et al. 2004). The technique is advantageous because it can provide rapid, non-destructive and multi-parametric measurements as well as being suitable for on- or in-line process control. Recent work has reported the utility of NIR spectroscopy for the prediction of sensory attributes and ripening stage of Cheddar (Downey et al. 2004) and Danbo (Sørensen & Jepsen, 1998) cheeses. A limited number of reports on the prediction of cheese texture using near infrared (Čurda & Kukačková, 2004) and fluorescence spectroscopy (Karoui & Dufour, 2003) have also appeared. Given that sensory and instrumental methods currently used to measure cheese texture are time-consuming and therefore costly, great interest exists in developing instrumental techniques to enable more objective, faster and less expensive assessments of cheese texture.

The present work is a preliminary investigation of the utility of NIR reflectance spectroscopy for the prediction of texture parameters obtained by sensory and mechanical testing in experimental processed cheese samples.

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Table 1. Ingredients, quantities and compositional targets used in the production of experimental processed cheeses

Processed cheese Sample number	Ingredients and quantities (g/kg)				Compositional targets (%)			
	Cheddar	Butter	Water	Emulsifier added	Moisture	Fat	Protein	Emulsifier added
Trial A								
1 & 10[1]	838·7	0·0	161·3	9·7	47·2	26·1	20·8	1·0
2 & nm[2]	838·7	0·0	151·2	19·4	46·2	26·1	20·8	2·0
3 & 11	838·7	0·0	141·9	29·0	45·2	26·1	20·8	3·0
4 & 12	838·7	51·6	112·9	9·7	43·0	30·2	20·8	1·0
5 & 13	838·7	51·6	100·0	19·4	42·0	30·2	20·8	2·0
6 & 14	838·7	51·6	90·3	29·0	41·0	30·2	20·8	3·0
7 & 15	838·7	100·0	61·3	9·7	38·8	34·3	20·8	1·0
8 & nm	838·7	100·0	51·6	19·4	37·8	34·3	20·8	2·0
9 & 16	838·7	100·0	41·9	29·0	36·8	34·3	20·8	3·0
Trial B								
1 & 9	848·4	51·6	103·2	9·7	42·4	30·6	21·0	1·0
2 & 10	838·7	51·6	100·0	19·4	42·0	30·2	20·8	2·0
3 & 11	829·0	51·6	100·0	29·0	41·6	29·9	20·5	3·0
4 & 12	751·6	45·2	203·2	9·7	48·9	27·1	18·6	0·9
5 & 13	745·2	45·2	203·2	19·4	48·4	26·9	18·4	1·8
6 & 14	738·7	45·2	200·0	25·8	48·1	26·6	18·3	2·6
7 & 15	651·6	38·7	303·2	25·8	54·8	23·5	16·1	1·6
8 & 16	645·2	38·7	303·2	22·6	54·6	23·3	16·0	2·3

[1] Number of the duplicate sample
[2] nm: duplicate not manufactured

Materials and Methods

Cheese samples

Samples (n=32) of processed cheese were manufactured at the Dairy Products Research Centre, Fermoy, Co. Cork with varying levels of Cheddar cheese, Irish commercial salted butter, water and emulsifying salt (disodium phosphate). Table 1 illustrates the proportion and amount (g/kg) of each ingredient used in the production of the processed cheeses, each of which weighed 3·1 kg. Cheddar cheese used for the production of the processed cheese was obtained from Dairygold in Mitchelstown, Co. Cork and had a maturity between 3–6 months. Ingredients were mixed for 1 min. in a jacketed cooker (Stephan UMM/SK5 Universal Machine, Stephan u Söhne GmbH & Co., Hameln, Germany) and cooked to 80 °C by indirect steam heating with constant stirring (knife at 300 rpm and baffle mixer at 80 rpm) for 2 mins. The resulting mixture was poured into food grade plastic containers (225 g capacity); these were then lidded, cooled and placed in storage at 4 °C. Cheese samples were manufactured in two separate trials (A & B) at two different times. In trial A, the designed compositional variation was in fat and emulsifying salt content whereas in trial B, moisture and emulsifying salt levels were varied. The design was executed in duplicate, with low, medium and high levels of moisture, fat and emulsifying salt in each trial. Table 1 gives compositional targets for each cheese sample which lie between 95·0 and 96·2%; the remaining 3·8 to 5% arises from ash content present in the Cheddar cheese and butter. These target values were selected to extend beyond those used commercially by processed cheese manufacturers. Trial A comprised 16 cheeses i.e. 9 samples (samples 1–9) plus 7 duplicates (samples 10–16) of those samples; two samples were not duplicated because of time constraints. In Trial B, 8 samples (samples 1–8) and 8 duplicates (samples 9–16) were manufactured. Duplicates were manufactured on different dates from the originals. In order to facilitate the study of the samples, samples from both trials were treated as one set of samples only.

Sensory analysis

Descriptive sensory analysis of cheese texture samples was carried out in University College Cork following 2 and 4 weeks storage at 4 °C. The panel of assessors comprised 9 females and 1 male aged between 35 and 55 years, selected and recruited in 1998 and 2000 from the Cork city region according to international standards (International Organisation for Standardisation, 1993). Descriptive sensory analysis on the experimental cheeses used a vocabulary of nine texture terms (Table 2). Prior to assessment, each cheese was cut into 5 g cubes, equilibrated to room temperature (21 °C), and presented in a covered glass tumbler, labelled with a randomly-selected 3-digit code. Cheeses were scored for attributes on unstructured 100 mm line scales labelled at both ends with extremes of each attribute. The intensity of each of the descriptive

Table 2. Vocabulary of texture attributes, definitions and mastication phases used in sensory analysis of processed cheese samples

Texture Attribute	Definition	Mastication phases
Firmness	The extent of the initial resistance offered by the cheese. Ranging from 'soft' to 'firm'.	Phase 1: Judged on the first chew using the front teeth.
Rubbery	The extent to which the cheese returns/springs to its initial form after biting. Ranging from 'a little' to 'a lot'.	Phase 2: Assessed during the first 2–3 chews.
Creamy	The texture associated with cream that has been whipped. Ranging from 'a little' to 'a lot'.	
Chewy	The effort needed to break down the structure of the cheese. Ranging from 'a little' to 'a lot'.	Phase 3: Judged in the middle phase of mastication.
Mouthcoating	The extent to which the cheese clings to the inside of the mouth (roof, teeth, tongue, gums). Ranging from 'a little' to 'a lot'.	
Fragmentable	Breaks down to smaller versions of itself. Ranging from 'a little' to 'a lot'.	Phase 4: Probably judged towards the end of the chewing.
Melting	The extent to which the cheese melts in the mouth. Smooth velvet fullness in mouth. Ranging from 'a little' to 'a lot'.	
Mass formation	The extent to which the cheese forms a bolus or mass in the mouth after chewing. Ranging from 'a little' to 'a lot'.	
Greasy/Oily	The extent to which a greasy/oily residue is deposited in the mouth after the cheese is broken down. Ranging from 'a little' to 'a lot'.	Phase 5: Judged at the end of the chewing sequence.

terms was recorded for each cheese using the Compusense sensory data acquisition programme (v.4.0; Guelph, Ont., Canada). At each time point (2 and 4 weeks), descriptive analysis took place over 2 d. The order of tasting was balanced to account for order of presentation and carry-over effects (MacFie et al. 1989).

Texture profile analyser (TPA) data collection

Textural properties of processed cheese were evaluated using the method of texture profile analysis (TPA). Texture measurements were performed on 60 samples only, since insufficient material was available for 4 cheeses. Cheese samples were cut into 25 mm cubes and each sample was compressed using a texture analyser (model TA HDi, Stable Micro Systems, Godalming, UK) with a 100 kg load cell and a 75 mm compression platen. A double bite compression cycle was used with a rest period of 3 s between bites; samples were compressed to 30% of original height at a speed of 4 mm/s during each bite. Strain gauges and a strip chart recorder produced a force-time curve from which a texture profile can be derived. Figure 1 shows an idealised stress-strain TPA curve (Szczesniak, 1963) and Table 3 describes the sensory definitions and formulations used to calculate instrumental texture properties studied in this work.

Meltability method

The method used (Wang & Sun, 2002) was similar to Schreiber's test as reported by Kosikowski (1982). Plugs of cheese (25 mm diameter, 5 mm height) for testing were extracted with a cork borer and a cheese wire; melted cheese was characterised by measuring the area of the spread (Muthukumarappan et al. 1999). Each sample was tested in triplicate at 2 and 4 weeks after manufacture and results were averaged.

NIR spectral collection

Reflectance spectra were collected between 750 and 2498 nm in 2 nm steps using a Foss NIRSystems 6500 spectrometer (FOSS NIRSystems, Silver Springs, MD). Instrument control and file manipulation was by WINISI II software (v. 1.04a; Infrasoft International, Port Matilda, MD). Spectral data were exported from the WINISI II software in JCAMP.DX format (Rutledge & McIntyre, 1992) and imported into The Unscrambler (v. 8.0; Camo A/S, Oslo, Norway) for data analysis. Because of the effect of temperature on the spectral response of high moisture samples such as cheese (Wehling & Pierce, 1988), all samples were equilibrated (~16 hours) to room temperature prior to NIR analysis. The actual temperature of cheese samples was measured immediately prior to analysis and ranged between 18 and 24 °C. Three cylinders (3·0 cm height × 3·8 cm diameter) were removed from each sample with a cork borer, placed in a circular reflectance cup and sliced to the cup depth (1·00 cm) using a flexible cheese wire. The central slice only from each of the three cores was retained and scanned thrice, with rotation of the sample cup through approximately 120° between successive scans. The average of all 9 spectra of each cheese sample was subsequently used for calibration development. The root mean square (RMS) values between the replicate scans for any given sub-sample were below 3000 micro-absorbance units.

Calibration development and validation

Spectral datasets, sensory and TPA measurements were examined by principal component analysis (PCA) to

Table 3. Name, description and method of calculation of instrumental texture terms studied (Parameters in each formulation refer to instrumental measurements in Fig. 1)

Terms	Description	Formulation
Springiness	Rubber behaviour	Ability of a material to recover its original state after first bite (c/a)
Cohesiveness	Resistance to sample separation into parts	Area of second bite divided by area of the first bite (A2/A1)
Chewiness	Number of chews required for swallowing	Hardness × Cohesiveness × Springiness
Adhesiveness	Stickiness of sample	Negative area after the first bite (B1)
Hardness	Forced required to bring the teeth together	Peak force recorded from the first bite

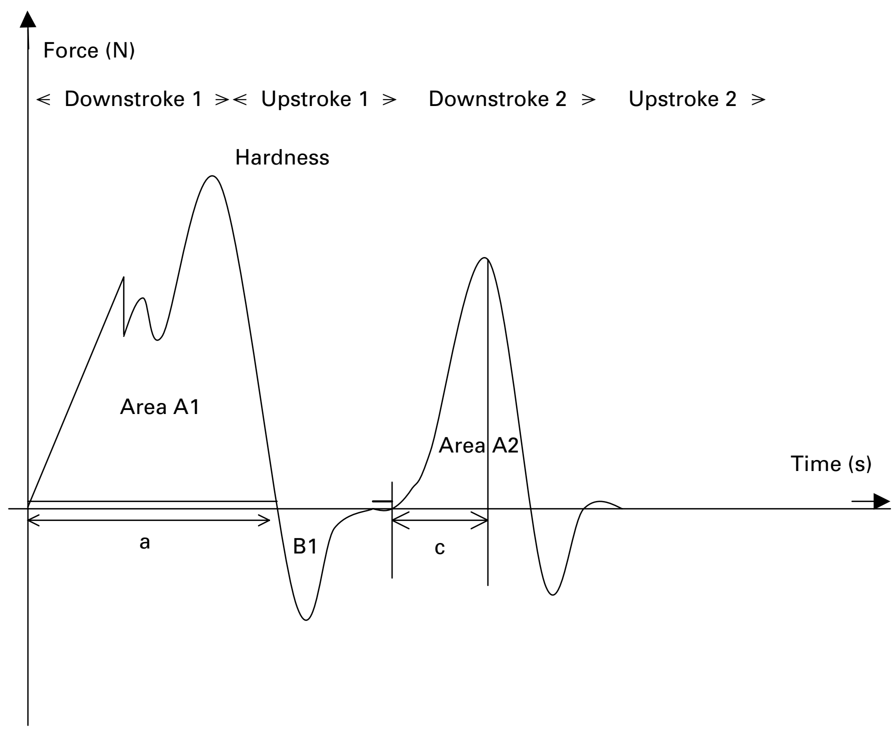

Fig. 1. An idealised stress-strain texture profile showing relationships to calculated instrumental texture terms (Szczesniak, 1963).

investigate differences and relationships between samples. Partial least squares regression (PLS1; Linusson et al. 1998) was utilised to develop calibration models for prediction of sensory, TPA and 'meltability' properties. Both PCA and PLS regression were performed using The Unscrambler. The correlation coefficient (R), root mean square error of cross-validation (RMSECV) and number of loadings (#L) were evaluated to assess the performance of each calibration model. The preferred predictive models were those with the lowest prediction error, a correlation coefficient as close as possible to 1 and the lowest number of loadings. The number of PLS loadings used in a given model show how well a variable is explained by the model components; it helps understand how much each variable contributes to the meaningful variation in a data set and to interpret relationships between variables (McElhinney et al. 1999). Due to the limited number of samples available, calibration models were generated using full (i.e. leave-one-out) cross-validation. Models were developed using two wavelength ranges, i.e. 750–1098 nm (near near infrared) and 1100–2498 nm (near infrared), and spectral data were input to multivariate processes in a number of forms: (1) no pre-treatment, (2) 1st derivative (2 datapoints each side; Savitzky & Golay, 1964), (3) 2nd derivative (4 datapoints each side), (4) after multiple scatter correction (MSC; Geladi et al. 1985) and (5) each derivative step followed by multiple scatter correction. The range error ratio (RER) was used to assess the practical utility of the calibration models (RER $\leqslant$ 3, little practical utility; 3 > RER < 10, limited to good practical utility;

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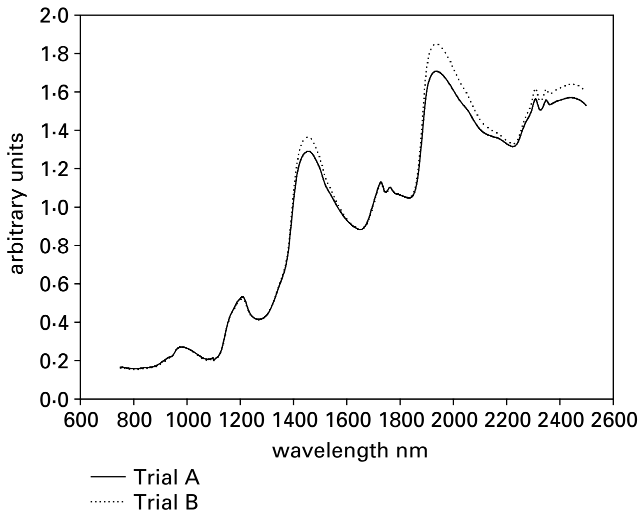

Fig. 2a. Mean of processed cheese reflectance spectra between 750–2498 nm for Trial A (n=32) and Trial B (n=32).

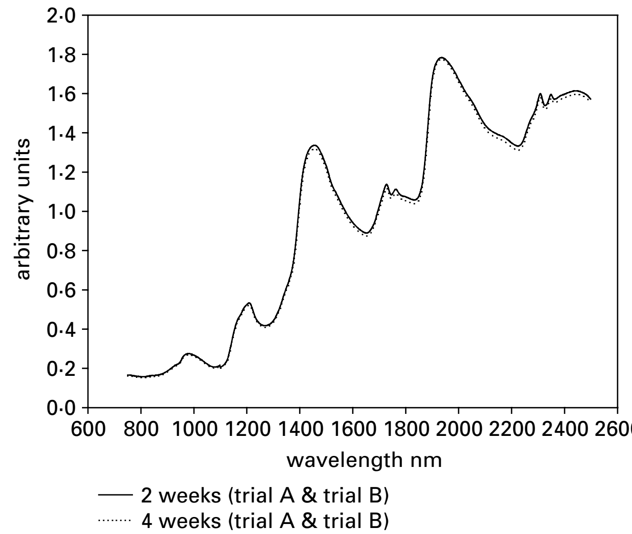

Fig. 2b. Mean of processed cheese reflectance spectra between 750–2498 nm for samples scanned 2 weeks and 4 weeks after manufacture (n=64).

RER>10, high utility value). Values for this ratio were calculated by dividing the range in each of the reference parameters by the relevant prediction error for that parameter (Williams, 1987).

Results and Discussion

Processed cheese spectral data

Figure 2a & b show the mean reflectance spectra of the 64 processed cheese samples studied and contain absorption bands characteristic of cheese constituents. Absorbance maxima at 970, 1450 and 1940 nm arise from water (Osborne et al. 1993) while lipid is responsible for bands at 1215, 1450, 1725, 1765, 2310 and 2347 nm (Osborne et al. 1993). In Fig. 2a, the mean of the NIR spectra collected for samples in Trial A is compared with the mean of samples in Trial B. Overall, they are very similar but absorbance variations arising from compositional differences can be clearly seen, viz. greater absorption by water bands at 1450 and 1940 nm for samples in Trial B. While the mean lipid content of Trial B samples is slightly lower than those in Trial A (27·3 *v.* 30·3 % w/w), the contra-indicated greater absorption by Trial B samples at 2310 and 2347 nm may be the result of a multiplicative effect on the spectra arising from the increased moisture content of these same samples. Figure 2b shows the mean spectra of samples collected for both trials after 2 and 4 weeks storage. Both curves are very similar, although after 4 weeks, absorption bands have slightly lower intensities, indicating the limited effect of storage period. A PCA analysis was carried out on the NIR spectra to interpret the effect of compositional variation on spectral data (Fig. 3). Samples are clearly distributed on the basis of moisture

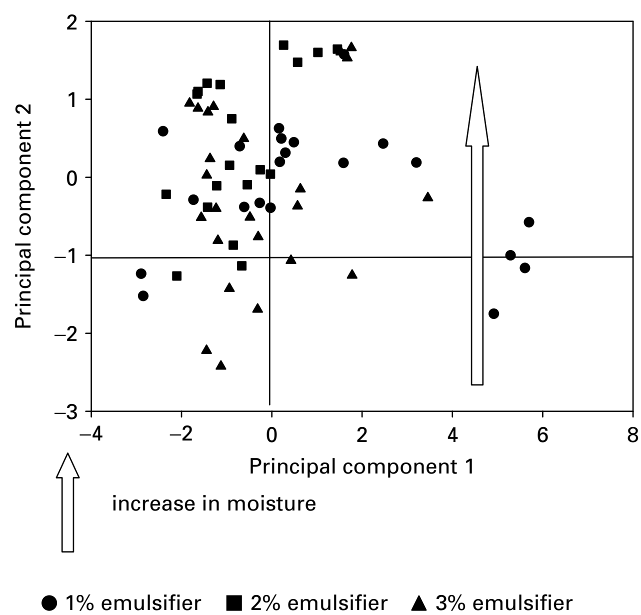

Fig. 3. PCA scores bi-plot of NIR spectra (750–2498 nm) from processed cheese samples after 2 and 4 weeks of storage.

and fat present; those located around the top of the plot have a higher moisture and lower fat content than samples found in the lowest region. There are four points in Fig. 3 that appear unusual and could be considered as outliers. They are duplicate scans of samples number 4 (scanned at 2 weeks) and 12 (scanned at 4 weeks) of Trial B (Table 1). No explanation has been found to explain the behaviour of these samples and they have therefore been retained in the dataset.

Table 4. Mean, range and standard deviation of the average results for each sensory attribute

Sensory attribute	Mean	Range	Standard deviation
Fragmentable	25·6	1·4–52·4	22·1
Firmness	37·6	5·6–70·9	21·9
Rubbery	23·3	2·9–44·6	14·4
Creamy	35·7	10·7–70·7	22·6
Chewy	24·8	2·8–46·1	14·6
Mouthcoating	33·1	17·4–54·8	10·0
Greasy/oily	36·6	28·5–43·8	3·9
Melting	40·1	13·2–82·5	23·6
Massforming	10·5	1·8–25·4	5·5

Table 5. Mean, range and standard deviation of the average results of the instrumental texture measurements; mean values were derived from four replicate measurements in each case

Texture descriptive terms	Mean	Range	Standard deviation
Springiness	0·28	0·17–0·82	0·1
Cohesiveness	0·22	0·14–1·82	0·2
Adhesiveness	18·3	5·2–37·8	7·6
Chewiness	5·7	1·24–13·2	2·7
Hardness	120·9	9·8–263·3	70·8
Meltability	79·3	41·4–243·6	40·4

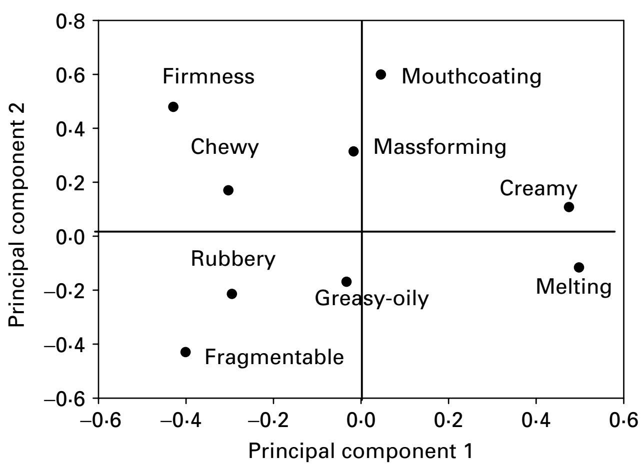

Fig. 4. PCA loadings bi-plot of sensory analysis data from processed cheese after 2 and 4 weeks of storage (PCs 1 & 2 explain 88 and 9% of the dataset set variance respectively).

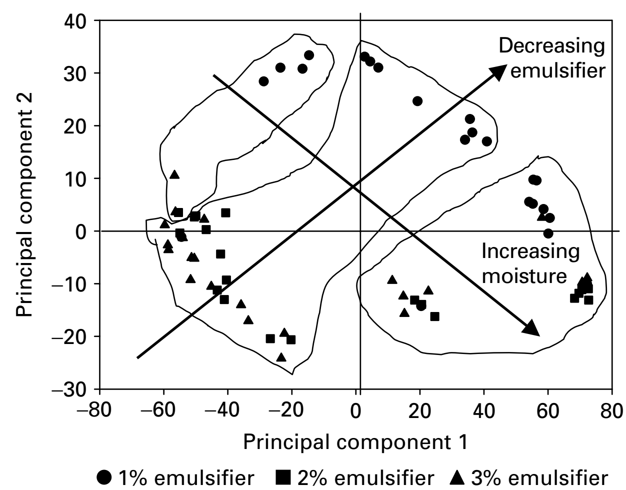

Fig. 5. PCA scores bi-plot of the sensory results from processed cheese samples ($n=64$).

Sensory data examination

A summary of the values obtained by the taste panel for each of the 9 sensory parameters at the 2 different time points is shown in Table 4. The standard deviations of these values were large, particularly for 'fragmentable', 'firmness', 'creamy' and 'melting'. From the point of view of multivariate calibration, wider ranges are beneficial for the development of robust and accurate calibrations. Figure 4 is a bi-plot of the loadings on the first two principal components (PCs); 'firmness', 'chewy', 'massforming', 'mouthcoating' and 'creamy' properties are located along principal component 1 and at the positive extreme of principal component 2 in opposition to 'fragmentable', 'greasy-oily', 'rubbery' and 'melting'. This distribution of the parameters is intuitively sensible, suggesting that 'firmness' is negatively correlated with 'melting' and 'mouthcoating' is opposed to 'fragmentable'. Figure 5 shows the corresponding scores plot. Samples are primarily arranged according to their moisture content with those in the top left cluster, the centre group and the bottom right cluster having low, medium and high moisture contents respectively. There is also an indication that within this broad grouping, samples are clustered according to the level of emulsifier (1, 2 or 3% w/w) used in their formulation. Comparison of the loadings and scores plots (Figs 4 & 5) shows that cheeses manufactured with high moisture and medium-to-low fat levels were described predominantly as 'creamy' and 'melting', whereas cheeses manufactured with lower moisture, high-to-medium fat and low emulsifier were chiefly described as 'firm' and 'mouthcoating'. Cheeses manufactured with medium moisture, medium-to-high fat, medium and high emulsifier content were described as 'fragmentable' and 'rubbery'.

Instrumental data examination

Values for the instrumental texture parameters are shown in Table 5 which reveals large differences between the mean, range and standard deviation values obtained particularly for 'hardness' and 'meltability'. Figure 6 shows the PCA results on this dataset and it is interesting to observe the closeness of 'springiness' and 'cohesiveness'

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Table 6. PLS prediction results for sensory parameters (1100–2498 nm, $n=64$; preferred models in bold)

	No pre-treatment				1st der[1]				2nd der[2]			
Sensory attribute	R	RMSECV	#L	RER	R	RMSECV	#L	RER	R	RMSECV	#L	RER
Fragmentable	0·94	6·7	4	7·6	0·94	6·6	5	7·7	0·94	6·8	8	7·5
Firmness	0·94	7·7	4	8·5	0·94	7·6	5	8·6	0·91	8·9	4	7·4
Rubbery	0·95	4·4	5	9·5	0·95	4·6	3	9·1	0·94	4·7	9	8·9
Creamy	0·96	6·1	5	9·8	0·97	5·9	5	10·3	0·95	7·1	5	8·5
Chewy	0·96	4·2	4	10·4	0·96	4·2	5	10·3	**0·97**	**3·6**	**9**	**12·0**
Mouthcoating	0·89	4·6	12	8·2	**0·89**	**4·6**	**10**	**8·1**	0·85	5·3	8	7·1
Greasy/oily	0·81	2·3	6	6·6	**0·80**	**2·4**	**4**	**6·4**	0·78	2·5	5	6·3
Melting	**0·97**	**5·9**	**4**	**11·8**	0·97	5·8	5	12·0	0·96	6·4	7	10·9
Massforming	**0·85**	**2·9**	**4**	**8·1**	0·87	2·8	6	8·6	0·86	2·8	5	8·3

	MSC[3]				1st der+MSC				2nd der+MSC			
Sensory attribute	R	RMSECV	#L	RER	R	RMSECV	#L	RER	R	RMSECV	#L	RER
Fragmentable	**0·95**	**6·5**	**4**	**7·9**	0·94	7·0	6	7·3	0·92	8·0	6	6·4
Firmness	**0·94**	**7·2**	**2**	**9·1**	0·93	8·1	4	8·1	0·93	7·9	5	8·3
Rubbery	**0·95**	**4·6**	**4**	**9·1**	0·93	5·4	4	7·7	0·91	5·8	6	7·2
Creamy	**0·97**	**5·8**	**5**	**10·3**	0·95	7·0	4	8·6	0·94	7·5	5	8·0
Chewy	0·96	4·1	3	10·6	0·95	4·6	4	9·5	0·95	4·6	6	9·4
Mouthcoating	0·88	4·7	11	7·9	0·87	4·9	9	7·7	0·84	5·4	8	7·0
Greasy/oily	0·81	2·3	9	6·6	0·80	2·4	10	6·4	0·71	2·8	6	5·4
Melting	0·96	6·8	3	10·3	0·96	6·3	5	11·1	0·96	6·8	6	10·2
Massforming	0·83	3·0	3	7·8	0·86	2·9	6	8·3	0·84	3·0	6	8·0

[1] Savitzky-Golay, 2 datapoints either side; 1104–2494 nm effective range
[2] Savitzky-Golay, 4 datapoints either side; 1108–2490 nm effective range
[3] Multiplicative scatter correction

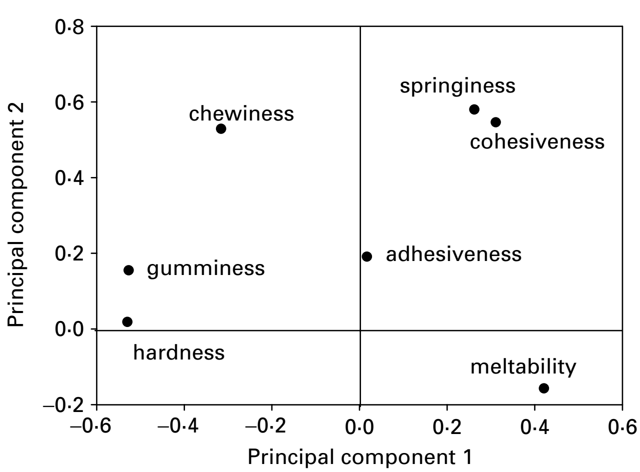

Fig. 6. PCA loading bi-plot for textural instrumental data, standardised to unit variance (due to large differences in magnitude and variability; Table 5), obtained by TPA and by computer vision (meltability) for processed cheese after 2 and 4 weeks of storage (PCs 1 & 2 explain 43 and 34% respectively of data set variance).

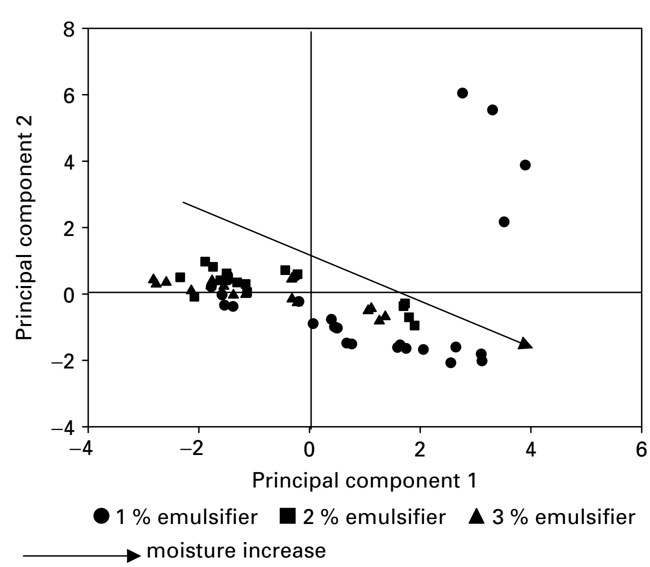

Fig. 7. Sample scores bi-plot for the instrumental texture measurements and 'meltability' (standardised data).

in the plot and their opposition to 'hardness'. Also in this figure, 'springiness', 'cohesiveness', 'adhesiveness', 'chewiness' and 'hardness' are on the positive side of PC2 in opposition to 'meltability'. Figure 7 shows a clear trend in sample location along PC1 on the basis of moisture content. There are 4 samples that appear as outliers (duplicates of samples 8 and 16 from Trial B; see Table 1). The texture of these samples resembled a cheese

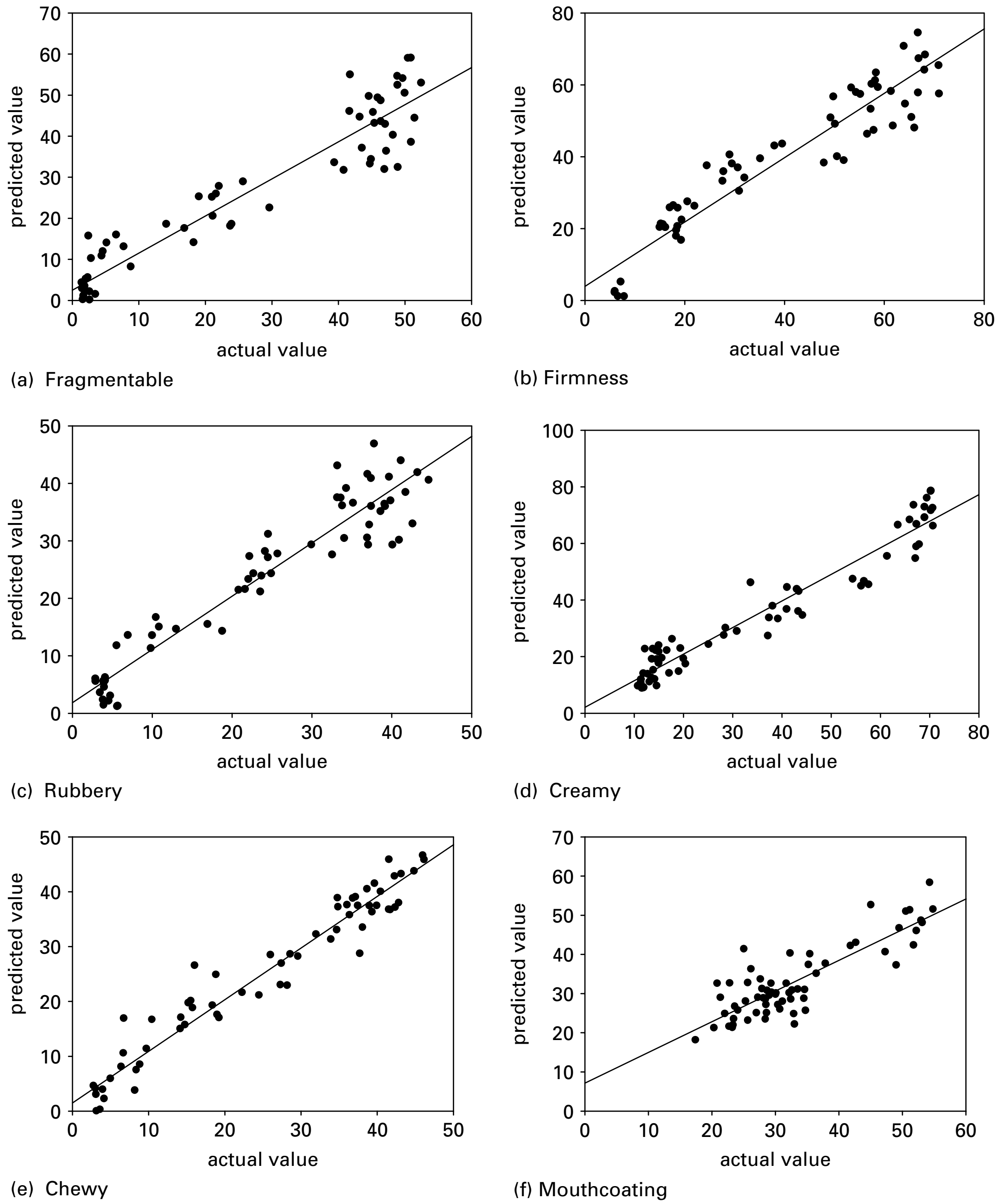

Fig. 8. Cont.

spread more than a solid cheese due to the high amount of moisture present i.e. they were physically very different from the rest of the samples. With regard to sample emulsifier levels, there is a suggestion of differentiation between samples with 1% and samples with 2 and 3% emulsifier.

Comparing the scores (Fig. 7) and loadings (Fig. 6) plots, samples with low/medium moisture score higher on 'hardness' or 'gumminess' scales while samples of high moisture content have larger 'meltability' values.

Prediction of sensory parameters

Calibration models to predict all 9 sensory attributes were developed using the 750–1098 nm and 1100–2498 nm wavelength ranges and the six data input options. Results obtained using the 750–1098 nm wavelength range were of similar but lower accuracy than those developed using spectral data between 1100 and 2498 nm; for this reason, only the models developed in the latter region are discussed further. No clear pattern emerged with regard to

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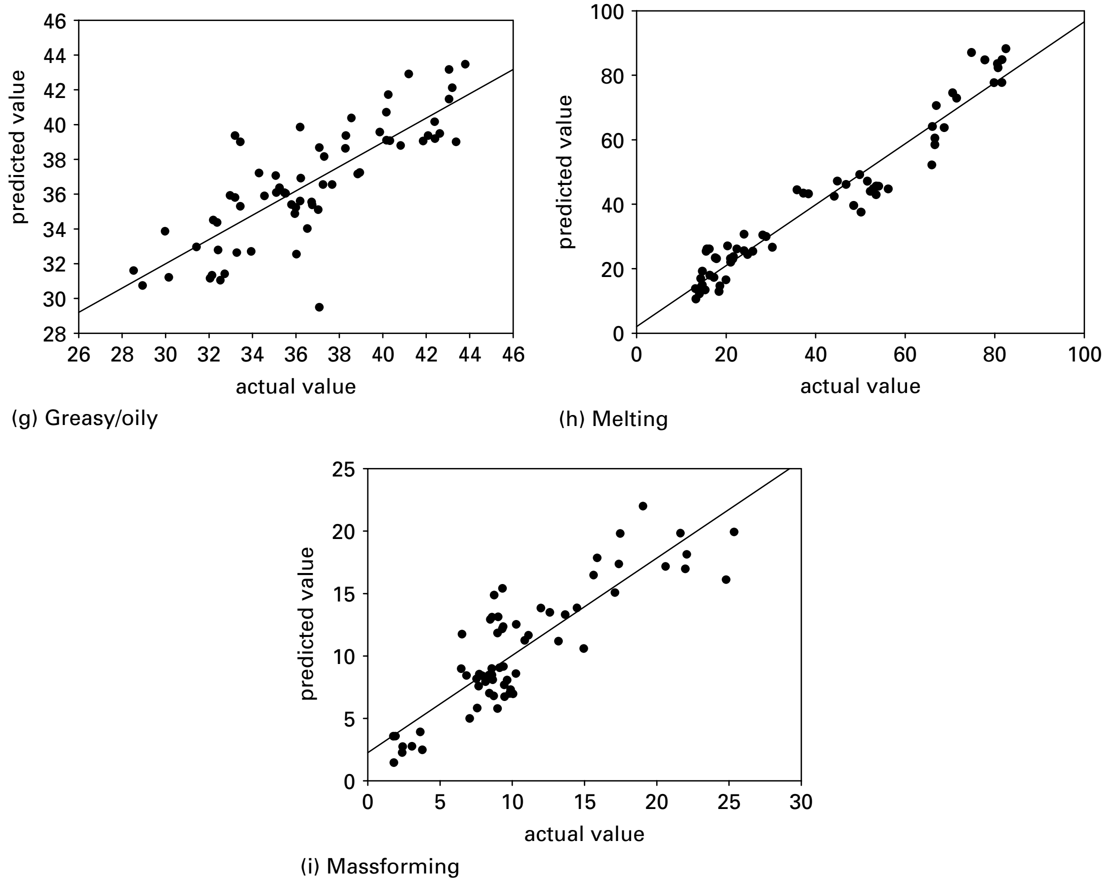

Fig. 8. Linear regression of preferred models for sensory parameters: (a) 'fragmentable' (MSC), (b) 'firmness' (MSC), (c) 'rubbery' (MSC), (d) 'creamy' (MSC), (e) 'chewy' (2nd derivative), (f) 'mouthcoating' (1st derivative), (g) 'greasy-oily', (h) 'melting' (no pre-treatment) and (i) 'massforming' (no pre-treatment) (Spectra collected between 1100 and 2498 nm, 64 samples).

the efficacy of any of the spectral pre-treatments investigated. In some cases, results obtained after the application of different treatments were very similar such as, for example, 'fragmentable' and 'creamy'. On the basis of the criteria established at the outset, preferred models for each of the sensory parameters studied are shown in bold type in Table 6.

The utility of these preferred models was assessed using RER values and all were found to have good-to-high-utility. 'Chewy', 'melting' and 'creamy' models yielded the highest RER values (12·0, 11·8 and 10·3 respectively) suggesting a high practical utility. 'Fragmentable', 'firmness', 'rubbery', 'mouthcoating', 'greasy/oily' and 'massforming' produced RER values of 7·9, 9·1, 9·1, 8·1, 6·4 and 8·1 respectively, suggesting good practical utility. Linear regression prediction plots of the preferred calibration models are shown in Fig. 8a–i. In the 'fragmentable' (Fig. 8a), 'firmness' (Fig. 8b) and 'rubbery' (Fig. 8c) plots, 3 clusters can be observed. The top cluster corresponds to samples with low moisture/high fat content, the cluster in the centre to samples with medium moisture/medium fat and the cluster at the bottom to samples with high moisture/low fat level. A similar but reversed clustering pattern is found for 'creamy' (Fig. 8d) and 'melting' (Fig. 8h) regression plots. In the case of the 'chewy' sensory attribute (Fig. 8e), samples are regularly distributed along the regression line according to the level of fat/moisture; samples at the top contain the highest fat content, with the lowest fat samples being found at the bottom. With 'massforming' (Fig. 8i), clustering of samples is less clear but a high-fat-top-cluster and high-moisture-bottom-cluster is present. For 'mouthcoating' (Fig. 8f) and 'greasy/oily' (Fig. 8g), no particular compositionally-related distribution of samples along the regression line was found. These sample distributions accord with results from the loadings (Fig. 4) and scores (Fig. 5) plots of the sensory data in which samples manufactured with low moisture/high fat are more 'rubbery', 'chewy' and 'firm' than samples with high moisture which are described as being more 'creamy' and 'melting'.

Table 7. PLS prediction results for instrumental texture attributes (1100–2498 nm, n=60; preferred models in bold)

	No pre-treatment				1st der[1]				2nd der[2]			
Texture attributes	R	RMSECV	#L	RER	R	RMSECV	#L	RER	R	RMSECV	#L	RER
Adhesiveness	0·69	5·6	11	5·0	0·73	5·5	12	5·2	0·57	6·4	5	4·5
Chewiness	0·87	1·4	16	5·1	**0·86**	**1·4**	**12**	**4·9**	0·81	1·6	11	4·3
Cohesiveness	**0·92**	**0·1**	**6**	**3·6**	0·96	0·1	12	5·3	0·95	0·1	11	4·3
Springiness	0·95	0·1	15	7·3	**0·97**	**0·1**	**12**	**7·3**	0·93	0·1	10	5·8
Hardness	**0·97**	**16·5**	**5**	**15·4**	0·97	17·2	5	14·8	0·96	19·3	6	13·1
Meltability	0·95	14·2	6	14·2	0·96	13·5	5	15·0	0·94	16·5	4	12·3
	MSC[3]				1st der+MSC				2nd der+MSC			
Texture attributes	R	RMSECV	#L	RER	R	RMSECV	#L	RER	R	RMSECV	#L	RER
Adhesiveness	**0·70**	**5·6**	**10**	**5·1**	0·71	5·6	11	5·1	0·49	6·7	3	4·3
Chewiness	0·87	1·4	19	4·8	0·85	1·5	13	4·7	0·77	1·8	11	3·9
Cohesiveness	0·91	0·1	7	3·6	0·94	0·1	11	4·3	0·94	0·1	12	4·3
Springiness	0·90	0·1	8	4·8	0·95	0·1	12	7·3	0·92	0·1	12	5·8
Hardness	0·96	18·7	2	13·6	0·96	18·8	4	13·5	0·96	20·8	5	12·2
Meltability	**0·97**	**12·4**	**6**	**16·3**	0·95	14·1	4	14·4	0·95	15·2	5	13·3

[1] Savitzky-Golay, 2 datapoints either side; 1104–2494 nm effective range
[2] Savitzky-Golay, 4 datapoints either side; 1108–2490 nm effective range
[3] Multiplicative scatter correction

In the absence of similar studies on processed cheese, results obtained in the current study have been compared with those of similar studies for Cheddar cheese products (Downey et al. 2004). Cheddar parameters best predicted were 'rubbery', 'chewy', 'mouthcoating' and 'massforming' with RER values of 8·8, 6·3, 7·6 and 8·5 respectively. RMSECV values reported were 3·4, 4·0, 5·0 and 4·1, correlation coefficients were 0·82, 0·84, 0·78 and 0·79 and 5, 8, 8 and 7 loadings respectively were involved. Comparing RER values calculated in both studies, the current work produced better values than was the case for Cheddar cheese. Sørensen & Jepsen (1998) applied NIR reflectance and transmittance for the prediction of flavour and consistency attributes in semi-hard Danbo cheeses. In general, they found better results in reflectance than transmittance mode. They obtained better results for consistency ('springy', 'sticky', 'coherent', 'soluble' and 'hard') attributes (R=0·74–0·88, standard error of prediction, SEP=0·64–1·54) than for flavour ('cheesy', 'acid', 'sweet' and 'unclean') attributes (R=0·27–0·59, SEP=0·58–0·84).

Prediction of instrumental texture measurements

As was the case for sensory attributes, the most accurate NIR reflectance calibrations were obtained in the wavelength range between 1100–2498 nm (Table 7); models produced using spectral data from 750–1098 nm will not be discussed.

The most important characteristic of the models was that the #L used to develop them was quite high. In 23 out of the 42 developed, #L was $\geqslant$10; this may have implications for the robustness of the models as, the lower the number of loadings, the more robust the model. Another interesting feature is the fact that the number of loadings does not always decrease as pre-treatments are applied. In general, the calibrations obtained yielded very similar results and again, no clear pattern with regard to pre-treatment use was discernible. The preferred calibration models are shown in bold type in Table 7. Regression plots of the preferred prediction models for each instrumental texture measurement term are plotted in Fig. 9. There was no clear, composition-related distribution of samples in the case of 'chewiness' (Fig. 9b) or 'cohesiveness' (Fig. 9c) although a number of samples with low moisture content were found at the top of the plot and some with high moisture found at the bottom. In the case of 'cohesiveness' (Fig. 9c) and 'springiness' (Fig. 9d), sample distribution along the regression line was very irregular, with the majority clustered at the lower end of the line. Duplicate results for two samples (numbers 8 & 16, Trial B; Table 1) were separated from the main cluster of samples in both plots; these contained the highest moisture and lowest fat content of all the sample set. In 'hardness' (Fig. 9e) linear regression, a more regular distribution of samples was found; samples at the top of the line had a lower moisture content than samples found at the bottom of the line. There was no clear compositional distribution for 'meltability' (Fig. 9f). The RER values obtained for 'chewiness' (4·9), 'cohesiveness' (3·6) and 'springiness' (7·3) suggest limited-to-good practical utility for these models. 'Hardness' (15·4) and 'meltability' (17·6) yielded RER values indicating a high practical utility for the models.

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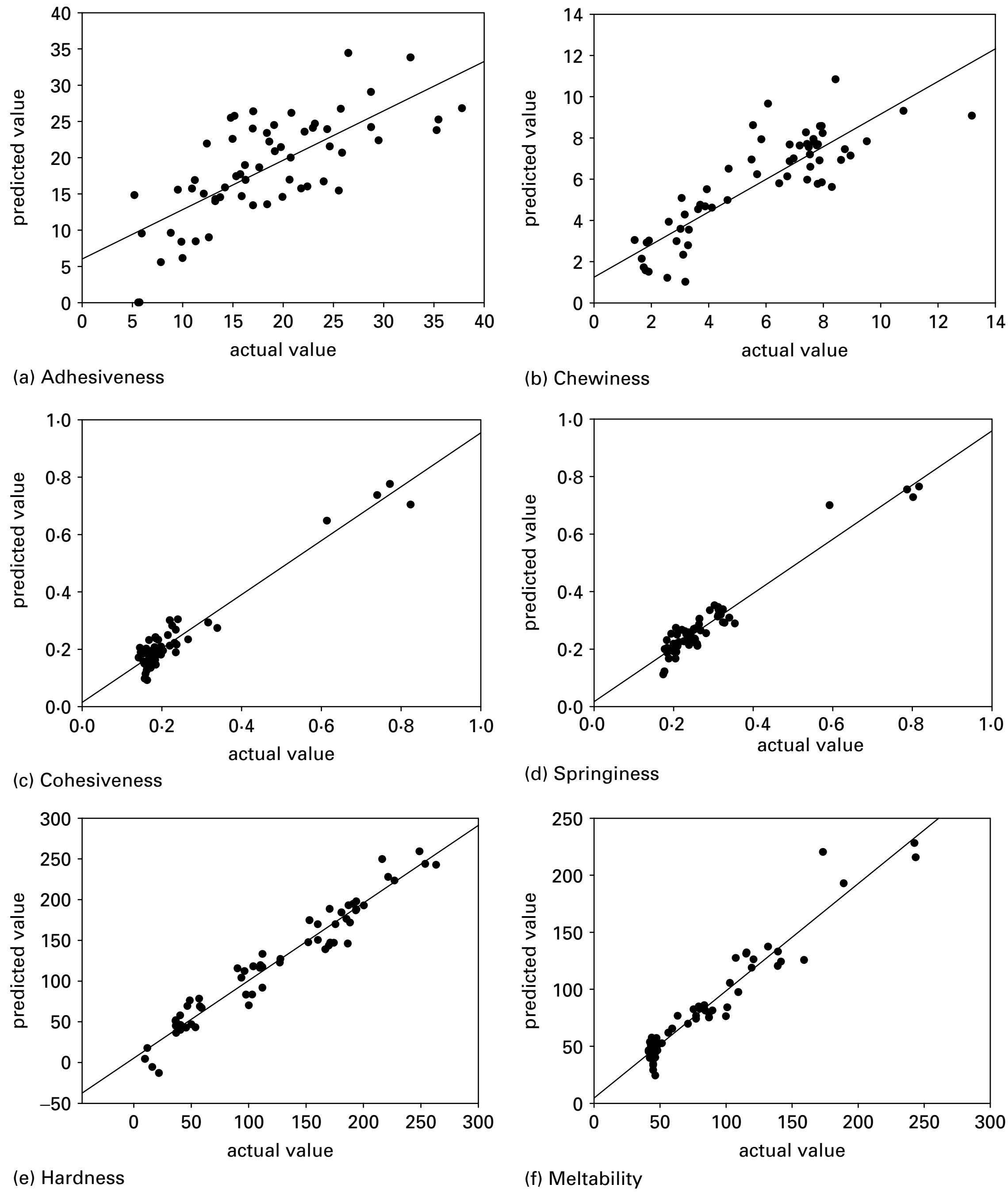

Fig. 9. Linear regression of preferred models for instrumental texture parameters: (a) 'adhesiveness' (MSC), (b) 'chewiness' (1st derivative), (c) 'cohesiveness' (no pre-treatment), (d) 'springiness' (1st derivative), (e) 'hardness' (no pre-treatment) and (f) 'meltability' (MSC) (Spectra collected between 1100 and 2498 nm, 60 samples).

In summary, multivariate statistical analysis of NIR spectroscopic data is a very powerful tool for the prediction not only of cheese constituents, but also more complex quality parameters obtained by sensory testing and instrumentally-measured parameters. This initial study demonstrates that NIR reflectance can be used to predict many sensory and instrumental sensory parameters with a level of accuracy suitable for industrial use. Larger studies involving commercially-produced cheeses will be required to confirm this.

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