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Relating the sensory sensation 'creamy mouthfeel' in custards to rheological measurements

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Characteristics of food products are commonly assessed in series of sensory studies to gain insight which can be used, for instance, for product development. Sensory studies are very time-consuming and susceptible to large sources of variation. Assessing information about (new) products by means of instrumental measurements would be very beneficial for numerous reasons, including repeatability, reproducibility and, most of all, the fact that instruments do not suffer from fatigue or adaptation. Measurements simulating sensory assessment of product properties can be performed at different stages of consumption and on different types of sensory attributes. In this study the relation between rheological parameters and creamy mouthfeel was investigated. The goal was to discover whether a model using a limited mechanical characterization, namely parameters describing bulk rheological behaviour, would suffice to describe the sensory attribute 'creamy mouthfeel', also called creaminess. The two main reasons for performing this study were (i) to investigate the possibility of using rheological measurements for high-throughput screening of newly developed custard products without the need for involving sensory panels already at an early stage of product development and (ii) to gain knowledge about the correlation between rheological measurements and the multidimensional attribute creamy mouthfeel. The resulting model shows that prediction of creamy mouthfeel by means of rheological measurements is possible only to a certain extent ($Q^2_{CV} = 0.48$). Reasons that can be mentioned for deviations between measured creaminess and modelled creaminess are (i) variation in measured creamy mouthfeel scores (variation in y-variable) and (ii) lack of description of surface properties of the food product by the rheological measurements used here. The results show that instrumental measurements are complementary to sensory analysis and can greatly facilitate the task for the practitioner at an early stage of product development, making high-throughput screening of novel products feasible. Copyright © 2005 John Wiley & Sons, Ltd.

KEYWORDS: rheology; sensory; creamy mouthfeel; PLS regression

1. INTRODUCTION

The characteristics of food products are commonly assessed in series of sensory studies to obtain information for several reasons ranging from getting detailed insight (expert panels) to getting to know the preferences of the consumer (consumer studies). These types of studies are very time-consuming and susceptible to large sources of variation. Assessing information about (new) products by means of instrumental measurements would be very beneficial for numerous reasons, including repeatability, reproducibility and, most of all, the fact that instruments do not suffer from fatigue or adaptation. Measurements can be performed at different stages of consumption and on different types of sensory attributes. In this study the relation between rheological parameters and creamy mouthfeel was investigated. Creamy mouthfeel is a sensation normally assessed orally on the tongue and palate; it is associated with fat content and a full sweet taste and can be described as a velvet, smooth and not rough or dry feeling, with a velvety coating on the tongue and palate [1].

Oral processing involves a complex series of manipulations by which both physical and chemical properties of the food change owing to interactions with saliva and the oral mucosa. This results in mechanical and enzymatic

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breakdown, dilution and equilibration to mouth temperature. Indications have been found that creaminess depends on properties originating from both the bulk and the outer layer (surface) of the bolus [2,3]. Creaminess has been related to multiple food properties, including smoothness, thickness [4] and specific flavours [5–7]. In order to understand a complex sensation such as creaminess [8] completely in terms of the physicochemical mechanisms underlying the sensation, bulk and thinfilm rheological (tribological) behaviour, in the presence of saliva, should be characterized [3,9–13]. In this paper a rheological characterization was done by performing dynamic small-deformation measurements to characterize the initial undisturbed structural state and the start of breakdown of the structure, by determining dynamic moduli and critical stress and strain values. Oral processing conditions also involve large deformations and these are not mimicked by small-deformation measurements. Therefore large-deformation mechanical properties were also characterized, in this case under shear. To this end, flow curves were measured describing the evolution of shear thinning. Finally, steady shear rate measurements were performed at a shear rate relevant for oral processing [14].

In order to understand how well instrumental measurements as used in this study are able to predict the sensory attribute creamy mouthfeel, a sensory regression model is presented first. This model can then be used to reflect to a better extent how well the model using only instrumental measurements would function in a real life experiment. Finally, after presenting both the sensory and instrumental regression models for creamy mouthfeel, the sensory and instrumental measurements are combined and analysed using principal component analysis. This exploratory analysis shows how the instrumental measurements reflect the sensory scores.

2. MATERIALS AND METHODS

2.1. Materials

Four series (Vk, Vm, Vo and Vp) of model vanilla custards were produced at a pilot plant by NIZO food research (Table I). Custards consisted of different types of modified starch (AVEBE, Veendam, The Netherlands) or Carboxymethylcellulose (CMC) (Akucell AF 3295, AKZO Nobel, Amersfoort, The Netherlands). Starch types were Farinex VA40, VA70, WM35, WM50, WM55, WM75 and VA50T. VA40 and VA70 were used as such and also after sieving (wind sifter ATP50, Hosokawa-Alpine) into three fractions. Mean diameters d_{30} of VA40 fine, middle and coarse were 22, 43 and 63 μm respectively and of VA70 fine, middle and coarse 23, 53 and 66 μm respectively (Helos laser diffraction). VA40 and VA70 are both potato starches, with VA40 being intermediately crosslinked and VA70 highly crosslinked. All WM types are waxy maize based, with crosslinking ranging from low (WM35) to rather high (WM75). VA50T is an intermediately crosslinked tapioca starch.

All custards contained 6% (w/w) sugar and 0.1% (w/w) vanilla flavour (3912, Danisco). Fresh milk was standardized at the required fat content at NIZO Food Research. Milk fat contents varied between 0.5% and 5%. For some model products, homogenized milk was used (two-stage

Table I. Composition of model custards

Type of thickener[a]	Thickener (%)	Milk fat (%)	Codes	Type of thickener[a]	Thickener (%)	Milk fat (%)	Codes
VA40	3.5	3.0	Vp11	WM35	3.4	3.0	Vo10
VA40	3.8	0.5	Vp08	WM35	3.7	3.0	Vo11
VA40	3.8	3.0	Vp12	WM50	3.6	5.0	Vk10[b], Vk25, Vm01[b], Vm16
VA40	4.1	0.5	Vp09	WM50	3.8	5.0	Vk11[b], Vk26, Vm02[b], Vm17
VA40 fine	4.3	3.0	Vo01	WM50	4.0	5.0	Vk12[b], Vk27, Vm03[b], Vm18
VA40 fine	4.6	3.0	Vo02	WM50	4.2	5.0	Vk13[b], Vk28, Vm04[b], Vm19
VA40 fine	4.9	3.0	Vo03	WM55	3.7	3.0	Vo25
VA40 middle	4.0	3.0	Vo04	WM55	4.0	3.0	Vo26
VA40 middle	4.3	3.0	Vo05	WM75	3.7	3.0	Vp04
VA40 middle	4.6	3.0	Vo06	WM75	3.9	0.5	Vp01
VA40 coarse	3.7	3.0	Vo07	WM75	4.0	3.0	Vo13, Vp05
VA40 coarse	4.0	3.0	Vo08	WM75	4.2	0.5	Vp02
VA40 coarse	4.3	3.0	Vo09	WM75	4.3	3.0	Vo14
VA70	4.1	5.0	Vm05[b], Vm20	VA50T	2.3	5.0	Vk18[b], Vk33, Vm09[b], Vm24
VA70	4.3	5.0	Vm06[b], Vm21	VA50T	2.5	5.0	Vk19[b], VK34, Vm10[b], Vm25
VA70	4.5	5.0	Vm07[b], Vm22	VA50T	2.7	5.0	Vk20[b], Vk35, Vm11[b],Vm26
VA70	4.7	5.0	Vm08[b], Vm23	VA50T	2.9	5.0	Vk21[b], VK36, Vm12[b], Vm27
VA70 fine	4.5	3.0	Vo16	CMC	0.42	3.0	Vp18A
VA70 fine	4.8	3.0	Vo17	CMC	0.46	0.5	Vp15A
VA70 fine	5.1	3.0	Vo18	CMC	0.50	3.0	Vp18
VA70 middle	4.2	3.0	Vo19	CMC	0.55	0.5	Vp15
VA70 middle	4.5	3.0	Vo20				
VA70 middle	4.8	3.0	Vo21				
VA70 coarse	3.9	3.0	Vo22				
VA70 coarse	4.2	3.0	Vo23				
VA70 coarse	4.5	3.0	Vo24				

[a]VA40, VA70, WM35, WM50, WM55, WM75 and VA50T were all Farinex types.
[b]Model product made with homogenized milk.

homogenization with a Rannier homogenizer at 200/20 bar). All raw materials used were of food grade quality.

Dairy custards (mixtures of the ingredients milk, starch, sugar and vanilla flavour) were produced by preheating to approximately 75°C and then UHT heating (indirectly) for 5 s at (pilot plant scale) 144°C in a tubular heating system (Combitherm, NIZO food research, The Netherlands). Next the custard was cooled to below 20°C before being aseptically filled, under sterile conditions, into beakers of capacity 0.5 l. For each type of custard a quantity of 6–9 l was produced. All custards were stored at 4°C.

2.2. Sensory measurements

The sensory properties of the custards were investigated using a sensory panel trained according to the principles of quantitative descriptive analysis (QDA) [15]. Assessors were selected for their sensory capabilities, were trained with the samples later used for measurement and were paid for their participation. Emphasis in the training was on mouthfeel and afterfeel attributes, odour and flavour attributes were kept limited. QDA panel testing took place at the sensory facilities of TNO Quality of Life, Zeist, The Netherlands. Panellists rated odour attributes, flavour/taste attributes, mouthfeel attributes and aftertaste/feel attributes. The attributes appeared per category on a monitor with a 100-point visual analogue scale (VAS) anchored at the extremes. Responses were indicated using a computer mouse. The odour attributes were rated first. Then the food was taken into the mouth, after which the taste/flavour and mouthfeel attributes were rated in the order in which they were perceived. Finally, after swallowing, the afterfeel attributes were rated. Panellists then rinsed their mouths before taking the next sample. A detailed description of the sensory measurements and the attributes used is given by de Wijk *et al.* [5] and Weenen *et al.* [16,17].

2.3. Rheological measurements

The custards were rheologically characterized using a Paar Physica MCR 300 rheometer with 40 mm flat, rough plates with a gap of 1 mm. Two types of small-deformation measurements were performed, via a dynamic (oscillatory) stress and frequency sweep, and two types of large-deformation measurements, namely determination of a flow curve and steady shear rate measurement. A logarithmically increasing stress from 0.01 to 100 Pa at a constant frequency of 1 Hz was used for the dynamic stress sweep. For the dynamic frequency sweep a stress of 0.2 Pa, within the linear viscoelastic region (LVER), at logarithmically increasing frequencies from 0.1 to 50 Hz was used. For the flow curve, apparent viscosities were determined at logarithmically increasing shear rates from 0.01 to 1000 s^{-1} (36 measuring points, each taking 15 s). For the steady shear rate measurement a shear rate of 10 s^{-1} was applied for 60 s, taking 200 measuring points logarithmically in time. All samples were allowed to relax and acclimatize for 5 min before starting a measurement. A cover was placed over the measuring system to prevent dehydration of the sample. For each measurement a fresh sample was loaded. All measurements were performed at 20°C and repeated at least once.

Collected data from rheological measurements (Table II) were input to multivariate modelling. The rheological input parameters were extracted (calculated) from rheological curves. An example of this procedure is shown in Figure 1 for a dynamic stress sweep. For example, dss-G′1 and G″1 are the storage and loss moduli respectively (measures of elastic and viscous properties respectively) measured at 1 Pa. For a more detailed description of dss-critstressA and B, see Table II. Horizontal parts of curves indicate the linear viscoelastic region where properties at rest are calculated. At the encircled point and at stresses higher than the critical stress the structure breaks up and the custard starts to flow. Parameters characterizing (large-deformation) flow cannot be extracted from this dynamic stress sweep, but originate from flow curves and steady shear rate measurements. Further details on extracted parameters are not relevant for this paper and will be further discussed in a paper by M. Terpstra *et al.* (unpublished work).

2.4. Data analysis

Two main data sets were used for this study: sensory data and rheological data. Both data sets were processed statistically with the computer program Matlab R13 (The Mathworks Inc.) using PLS Toolbox v3.0.2 (Eigenvector). The resulting models will be discussed in the next section. Validation is performed on the obtained models by performing LOO (leave-one-out) cross-validation. This results in a cross-validated correlation coefficient denoted as Q^2_{CV} throughout the paper. Besides multivariate analyses (PLS regression in this case), univariate statistics were also performed by means of ANOVA and Tukey tests (SAS v12) in order to test whether significant differences between samples could be found on individual parameters.

3. RESULTS AND DISCUSSION

3.1. Sensory results

Both sensory data and rheological data were analysed separately before correlating the rheological measurements with creamy mouthfeel. This helps in obtaining more insight about the information contained within each type of data. Sensory results are subject to a number of sources of variation due to individual differences between sensory scores. These differences can occur owing to, for example, differences between judges in sensitivity for certain attributes and differences in scale use. Among the sources of variation, intra-judge variation is also an important factor. This source of variation is reduced by averaging the sensory scores obtained from all assessors. The sensory data set contained 36 variables which can be subdivided into four main groups, namely mouthfeel, afterfeel, taste and flavour. Studies that were the subject of another paper [5] showed that creamy mouthfeel could successfully be predicted from a combination of flavours/tastes (creamy, fatty and absence of bitter/chemical and sickly flavours), mouthfeel attributes (thick, fatty and absence of rough mouthfeel) and fatty afterfeel. Two PLS latent variables (LVs) explained 85% of the variance in the regression variable creamy mouthfeel with $Q^2_{CV} = 0.81$. However, a model with flavour attributes included is difficult to compare with rheological measurements,

Table II. Overview of parameters extracted (calculated) from rheological measurements

Parameters	Codes[a]
Dynamic stress sweep (dss)	
• Dynamic moduli G' and G'', tanδ and strain γ at stress $\tau = 0.3, 1, 3, 5, 10, 33, 50, 100$ Pa	• dss-G′0.3, 1, 3, 5, 10, 33, 50, 100 dss-G′′0.3, 1, 3, 5, 10, 33, 50, 100 dss-tan0.3, 1, 3, 5, 10, 33, 50,100 dss-strain0.3, 1, 3, 5, 10, 33, 50, 100
• G', G'', tanδ and stress τ at strain $\gamma = 1\%$, 500%	• dss-G′1%, 500% dss-G″1%, 500% dss-tan1%, 500% dss-stress1%, 500%
• Critical stress and strain calculated as the crossover point of G' and G'' Critical stress and strain calculated as the maximal decrease in G' between two consecutive data points	• dss-critstressA, critstrainA dss-critstressB, critstrainB
• Break-up of the structure: decrease in G' and G'' between stress of 0.3 and 50 Pa Break-up of the structure: maximal decrease between two consecutive data points	• dss-dG′after, dG″after dss-dG′max
Dynamic frequency sweep (dfs)	
• G', G'' and tanδ at $f = 0.1, 1, 5, 10$ Hz	• dfs-G′0.1, 1, 5, 10 dfs-G″0.1, 1, 5, 10 dfs-tan0.1, 1, 5, 10
Flow curve (fc)	
• Viscosity η at shear rate $\dot{\gamma} = 0.1, 1, 10, 30, 50, 100\,\mathrm{s}^{-1}$	• fc-η0.1, 1, 10, 30, 50, 100
• Consistency K and shear-thinning index n from power law $\sigma = K\dot{\gamma}^n$ (calculated over shear rate range of 0.1–100 s^{-1})	• fc-K, n
• Constants from $\log\eta = A + B(\log\dot{\gamma}) + C(\log\dot{\gamma})^2$	• fc-polA, B, C
Steady shear rate (ssr)	
• Viscosity η at $t = 0.3, 0.5, 1, 3, 5, 10, 30, 60$ s	• ssr-η0.3, 0.5, 1, 3, 5, 10, 30, 60
• η and t at overshoot maximum of curve	• ssr-ηmax, tmax
• Difference in viscosity between overshoot maximum and $\eta(t = 0\,\mathrm{s})$, $\eta(t = 60\,\mathrm{s})$	• ssr-(max-b), (max-e)
• Relative stress maximum and decay fitted on decreasing part of the curve [18]	• ssr-fdτ, k

[a]All codes start with the name of the type of measurement they originate from and contain the specific point of the measurement that is represented; for example, dss-G′0.3 originates from a dynamic stress sweep and represents G' at 0.3 Pa.

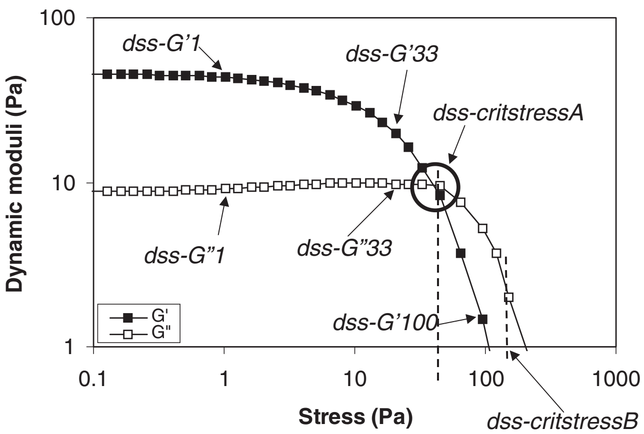

Figure 1. Example of results obtained with a dynamic stress sweep experiment. Indicated are some of the extracted parameters for modelling creaminess.

because rheological measurements are not related to flavour attributes. Therefore a new PLS regression model (sensory model in Table III) with the attributes rough, melting, thick, sticky, heterogeneous, fatty and airy (all mouthfeel attributes) was built to model the attribute creamy mouthfeel. Results of this model are shown in Figures 2(a)–2(c). Figures of merit for all models included in this paper are summarized in Table III. The procedure used to select relevant attributes for the sensory model was a mixture of the variable selection method called PLS-UVE [19] and expert knowledge when the choice between variables was not evident.

Although the results obtained from different judges tend to deviate from each other to a large extent, the underlying (sensory) PLS regression model appears to be able to predict creaminess to a large extent ($Q^2_{\mathrm{CV}} = 0.75$ and $Q^2_{\mathrm{test}} = 0.49$ with three LVs; total set of 60 samples split in half for a training and a test set of 30 samples each; seven sensory attributes). In the case described here, the obtained ratings for creamy mouthfeel ranged from 10 to 35 on a scale of 100. In total, 60 samples were tested, resulting in a matrix of 60 rows (samples) $\times$ 7 columns. In Figure 2(a) the loading plot is displayed showing the relations between the different variables. Figure 2(b) shows the PLS regression model using the complete data set of 60 samples. A jackknife procedure [20] was used to obtain an estimate of the variability of the regression coefficients. The results indicate that creamy mouthfeel is a complex multidimensional attribute with both positive contributions from the attributes thick, airy, sticky and fatty and negative contributions from rough mouthfeel, heterogeneous and melting. Since this paper mainly studies the relation between rheological measurements and creamy mouthfeel, the interested reader is referred to References [5,16] for further reading on the subject of creamy mouthfeel predicted by sensory measurements.

In Figure 2(c) a separate group of model custards is visible, with rather low creaminess ratings. All custards in this group are based on the same starch type (Farinex VA50T), which disintegrated extensively during production of the

Table III. Summarized model details: #LVs, number of latent variables of PLS regression model; r^2_{fit}, correlation coefficient of fitted data points; Q^2_{CV}, correlation coefficient, cross-validated, of training set; Q^2_{test}, correlation coefficient of prediction with independent test set, RMSECV, root mean square error of cross-validation; RMSEP, root mean square error of prediction. Both 'train' and 'test' models contain half (30) of the samples, whereas 'total' models contain the complete data set (60 samples).

Model		#LVs	r^2_{fit}	Q^2_{CV}	Q^2_{test}	RMSECV	RMSEP
Sensory	Train	3	0.83	0.75	—	3.1	—
	Test	3	—	—	0.49	—	4.9
	Total	3	0.81	0.77	—	3.0	—
Rheology	Train	4	0.66	0.34	—	5.3	—
	Test	4	—	—	0.37	—	5.2
	Total	4	0.66	0.56	—	4.2	—
Rheology simple	Train	1	0.51	0.43	—	4.7	—
	Test	1	—	—	0.43	—	4.9
	Total	1	0.53	0.48	—	4.5	

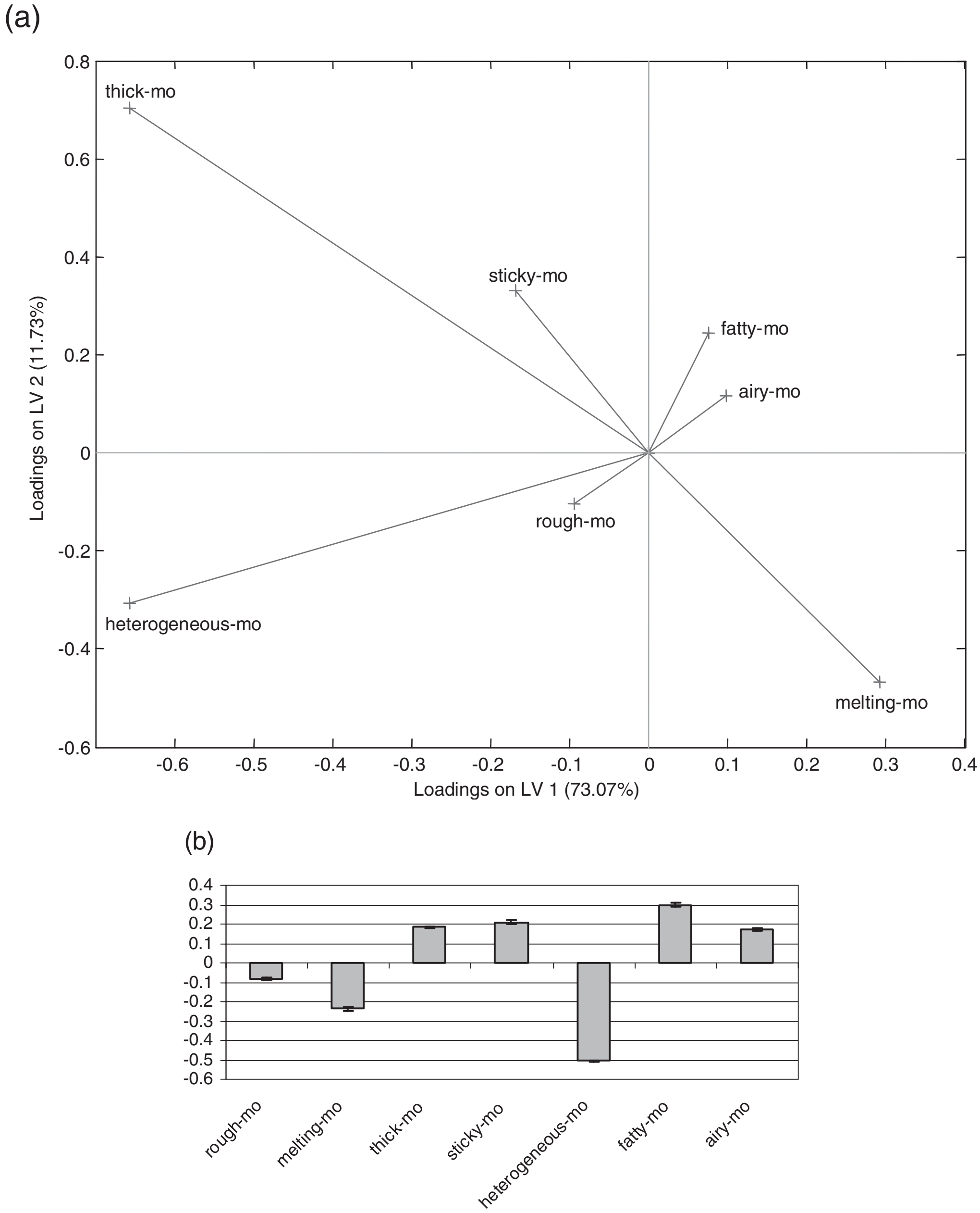

Figure 2. (a) Loading plot (PLS) for creamy mouthfeel (mo) (training set). (b) Regression coefficients for the PLS regression model (training set) predicting creamy mouthfeel (mo) from sensory attributes. Jackknife was used to obtain an estimate for the variation on the regression coefficients. (c) Score plot of sensory model (total set). Two distinct groups of samples are visible, which is due to different types of starch being used to prepare the products.

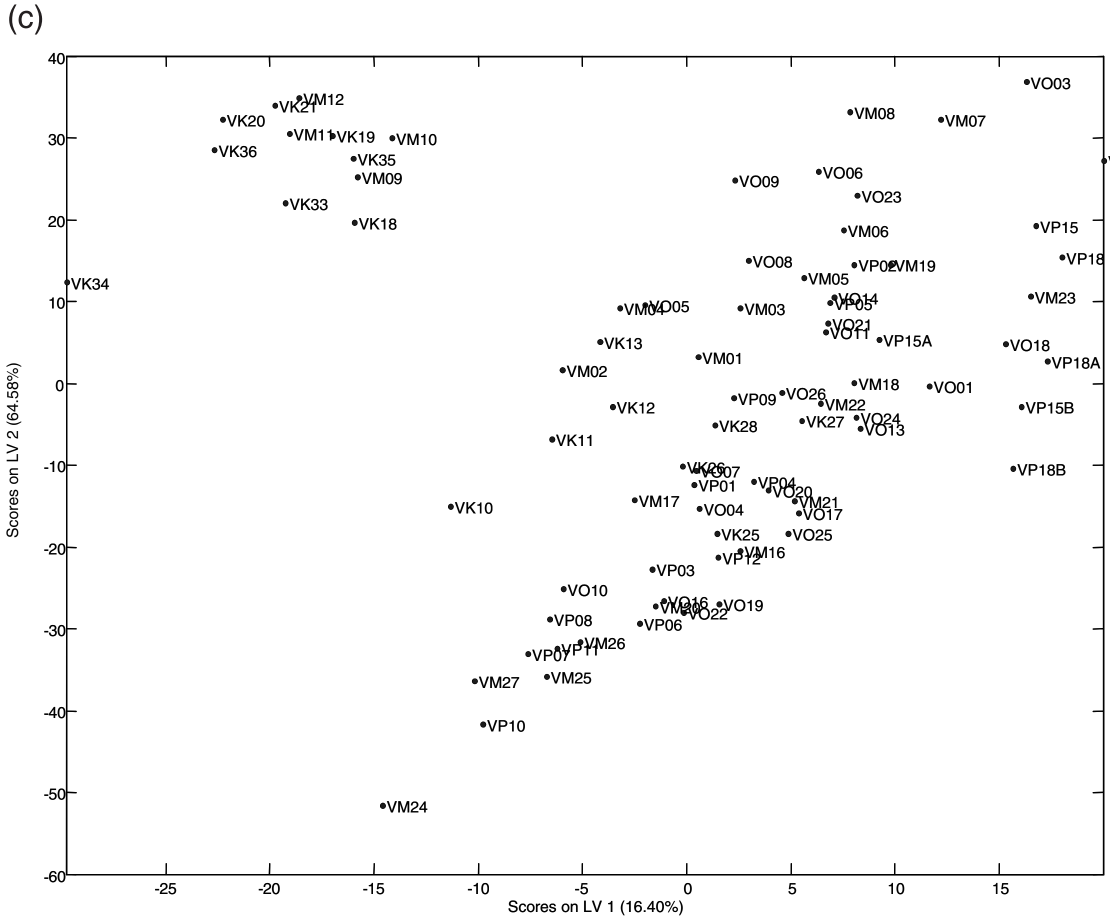

Figure 2. Continued.

custards, resulting in the highest heterogeneity ratings. Heterogeneity is negatively related to creaminess. Although different types of starch have been used, it was very difficult to obtain an even distribution of creaminess ratings along the predicted line, because, especially for the attribute heterogeneity, either high or low sensory ratings were obtained, with only a few custards with intermediate values.

3.2. Rheological results

A total of 84 rheological parameters were assessed for 60 samples. It is impracticable to perform all measurements for a high-throughput screening approach. Therefore variable reduction was needed. In order to assess which of the parameters should be retained, the following pre-screening strategy was used.

1. Perform a repeated measurements ANOVA with 'product' as main factor and determine with Tukey's test whether significant differences are present between the samples for each individual parameter. Tukey's test is used to test the mean of one population (repeated measurements in this case) against the mean of each other population.
2. Build a PLS regression model from the remaining data set and determine which of the variables have a non-significant contribution (regression coefficient not significantly different from zero, as calculated by means of a jackknife procedure) to the model.

The first step in the above strategy reduced the number of variables to be used in the model from 84 to 34. The rejected variables appeared to represent no significant differences between the samples. A variable was rejected when, over the complete data set, no significant differences could be detected. The number of variables was further reduced to 23 in the second step, in which minor variables (small regression coefficients) were rejected. Using ANOVA or any other univariate statistic to reduce the number of variables for a multivariate model has a limitation. It may happen that some variables do not have good discrimination ability from a univariate point of view but may contribute with other variables to the discrimination of the product. However, in the present case, ANOVA was used as a 'soft' pre-screening and the loss of power to discriminate was deemed less important than including erroneous variables.

The subset of 23 variables, obtained after building the PLS regression model in step 2, was divided into three groups each representing a different stage of the mechanical behaviour of the custards (Table IV). One group contains variables describing the properties of the custards at rest or at very small deformation, without break-up of the structure of the product. The second group is composed of variables

Table IV. Variables from the rheological PLS regression model predicting the sensory attribute creamy mouthfeel, assigned to subgroups. Variable dss-G″1 attributes to properties of both groups 1 and 2, ssr-η0.5 attributes to properties of both groups 2 and 3.

Group	Property	Parameters
1	Properties at rest	dfs-G″0.1, dfs-G″5, dss-G′1, (dss-G″1)
2	Structure break-up, start of flow	dss-critstressA, dss-critstrainA, dss-critstressB, dss-critstrainB, (dss-G″1), dss-G′33, dss-G″33, dss-G′100, dss-strain100, dss-G″500%, dss-dG′after, dss-dG′max, ssr-tmax, ssr-(max-b), ssr-fdτ, (ssr-η0.5)
3	Flow	fc-η100, fc-K, fc-polA, (ssr-η0.5), ssr-η60

related to the start of structure breakdown, i.e. where the custards really start to flow as a result of the applied stress or shear rate. Variables of the last group describe the way the products flow after (mechanically) breakdown of the structure.

Variables in group 1 originate from rheological data obtained in the so-called linear viscoelastic range, where applied stresses and strain are very small and do not affect the structure of the custards.

Variables representing the point of structure breakdown (group 2) are dss-critstressA and B and dss-critstrainA and B. This indicates where the viscoelastic behaviour of the custard changes from mainly elastic to predominantly viscous. For the majority of the samples, values of both critical stresses are lower than 33 and 100 Pa, so rheological parameters measured at 33 and 100 Pa describe flow behaviour just after structure breakdown. Similarly, dss-G″500% is part of group 2, as the values for critical strain are for most samples smaller than 500%.

Group 3 variables describe flow behaviour at large deformation and large shear rate. Most of the parameters from large-deformation measurements belong to this group. Exceptions are variables ssr-tmax, ssr-(max-b) and ssr-fdτ. These are highly correlated with dss-critstress and dss-critstrain and are part of group 2. Because these parameters are obtained at the beginning of the measurement, they represent the break-up of the structure. Although variable ssr-η0.5 is obtained just after starting the measurement, for about half of the samples it is obtained after the maximum viscosity is reached (ssr-tmax), for which reason it is a member of both groups 2 and 3.

The subset of 23 variables was still too large to be used in a high-throughput screening approach. Therefore rheological knowledge was used to assess whether variables have a similar physical basis and/or meaning. This resulted in a subset of 11 variables, representing the mechanical behaviour at rest, point of structure breakdown and start of flow and flow at large deformation, to be used for modelling creamy mouthfeel. The model built from all samples in the data set is shown in Figures 3(a) and 3(b). To test the model, the data were split amongst a training and a test set of 30 samples each. Estimates show that the error of the rheological model (RMSEP = 5.2 for the test set compared with RMSECV = 5.3 for the training set) is only slightly larger than the error of the sensory model (RMSEP = 4.9 for the test set compared with RMSECV = 3.1 for the training set).

The PLS regression coefficients are all significantly different from zero as assessed by means of jackknife testing (standard deviations shown, Figure 3(a)). For this set of prototype products a custard with a high creaminess rating is related to a high initial stiffness of the product, the structure breaks down at a low stress or strain (deformation) and then the product flows relatively easily. This finding is in agreement with results obtained for commercial custards [3]. The correlation between measured and predicted creamy mouthfeel by means of rheological measurements is shown in Figure 3(b).

Despite the fact that the model was based only on bulk properties rather than on bulk and surface-related properties, the prediction of creaminess by the model was still satisfactory. Besides rheological properties, also characterized in the presence of saliva [3], other properties of a product, such as physiological measurements [2], are needed to complete the information for predicting creamy mouthfeel without the use of sensory panels.

Further reduction of the number of variables is still possible. By using just data from one type of rheological measurement, i.e. a dynamic stress sweep (dss-G″33, dss-critstrainA and B), creaminess can be predicted rather well: $Q^2_{CV} = 0.43$, $Q^2_{test} = 0.43$, RMSECV = 4.7 and RMSEP = 4.9 using one latent variable. These variables represent the behaviour at break-up of the structure and start-up of flow. This means that, for screening of samples before sensory analysis, in fact just one rheological measurement can be used. One should keep in mind, however, that, when new products which deviate for other properties not monitored by these variables are put into the model, this may result in large deviations between true and predicted creaminess. To circumvent this problem, two solutions can be outlined: (i) spot checks by sensory analysis on a certain percentage of screened products or (ii) extension of the model for a broader field of products.

To obtain a feeling for the correlation between the sensory measurements and the reduced set of rheological measurements, the sensory and rheological data sets were combined and a consensus principal component analysis (consensus PCA) [21] was performed, resulting in the loading plot shown in Figure 4. Creamy, airy and fatty mouthfeel are related and they clearly relate negatively to rheological variables describing break-up of the structure (ssr-fdτ, ssr-tmax, dss-critstrainA); thus, when break-up of the structure is at low deformation, ratings for these three attributes are high. Heterogeneous mouthfeel, however, relates positively

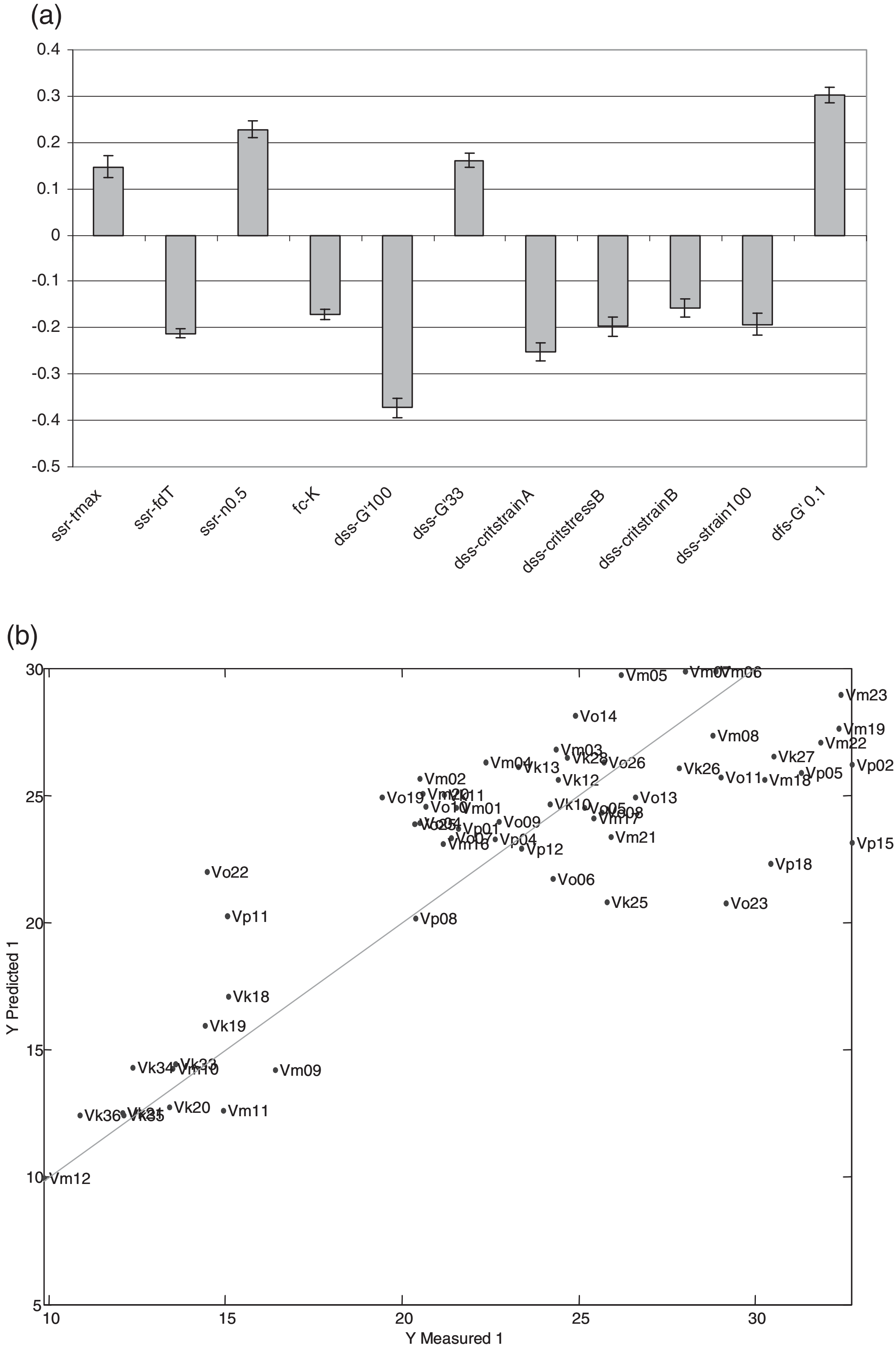

Figure 3. (a) Regression coefficients for the PLS regression model (training set) modelling the sensory attribute creamy mouthfeel. Standard deviations of the regression coefficients were estimated using jackknife (ssr-fdT = ssr-fdτ and ssr-n0.5 = ssr-η0.5). (b) Measured creamy mouthfeel versus values predicted by means of rheological variables.

to these rheological variables, indicating that heterogeneous custards can be deformed strongly (high dss-critstrainA) and demonstrate elastic behaviour longer (high ssr-tmax). The related attributes thick and sticky mouthfeel are positioned close to variables dss-G′100, dss-critstrainB and fc-K and are thus related to (the start of) the flow behaviour. This means that, to assess thickness and stickiness, the product needs to be deformed in the mouth. Melting is negatively related to thickness, thus also negatively related to the three mentioned variables for thickness. Although rough mouthfeel is

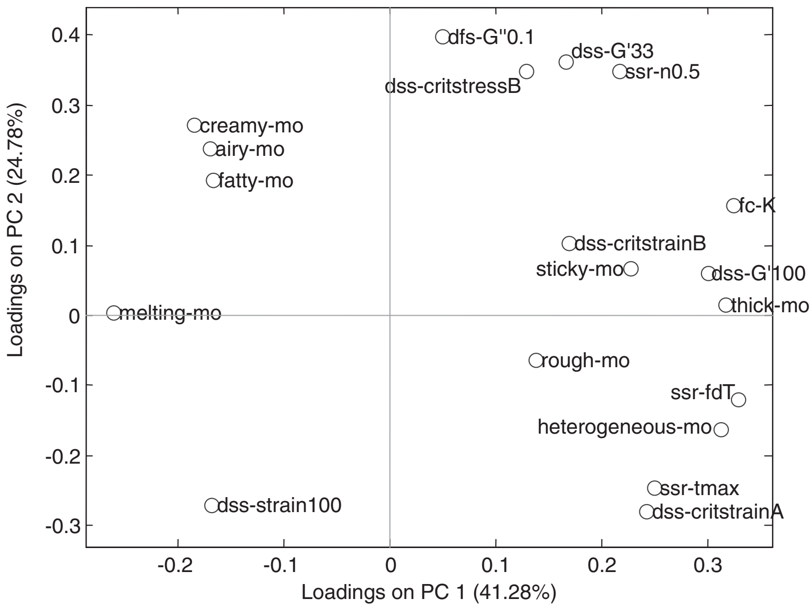

Figure 4. PCA plot of both rheological variables and sensory attributes (total set) showing the correlations between the various variables. Explanations and relevance of the correlations can be found in the text (ssr-fdT = ssr-fdτ and ssr-n0.5 = ssr-η0.5).

strongly negatively related to fatty mouthfeel, it hardly relates to any of the rheological variables. Rough mouthfeel is to a large extent determined by surface properties of the food bolus in the mouth [2,3], and these are not quantified by the rheological measurements described here.

4. CONCLUSIONS

Semi-solid fat-containing foods such as custards, mayonnaises and sauces are appreciated by consumers because of their creamy mouthfeel. This sensory attribute is difficult to describe and is known to be multidimensional. It was demonstrated that creamy mouthfeel in custards can be predicted reasonably well ($Q^2_{CV} = 0.48$) from rheological measurements; even a model based on just one type of rheological measurement is satisfactory. The mentioned rheological measurements only describe the bulk properties of the product, while creamy mouthfeel has contributions from both bulk and surface properties. To improve the model, a further step could be taken and surface properties could be added to the model in order to have a fully instrumental method for assessment of the sensory attribute creamy mouthfeel except for flavour and taste attributes.

The rheological model obtained so far ($Q^2_{CV} = 0.48$ and only three variables included compressed to one latent variable) can easily be used to perform high-throughput screening of newly developed products. Only those products that have a potential to be appreciated on the sensory attribute creamy mouthfeel need then be passed to sensory tests, thereby reducing the amount of sensory testing to be performed. The results show that instrumental measurements are complementary to sensory analysis and can greatly facilitate the task for the practitioner at an early stage of product development, making high-throughput screening of novel products feasible. It should, however, be stressed that instrumental measurements will never be able to replace sensory studies completely, as results obtained from instruments will only contain those product variations that the instruments were designed to detect.

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