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Original article

Correlation between instrumental and sensory ratings by evaluation of some texture reference scales

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Summary The objective of this study was to investigate instrumental–sensory relationships of some texture scales using argentine foods as references. Textural characteristics of these foods were instrumentally investigated by the texture profile analysis technique. Principal component analysis (PCA) was used to describe the main attributes of the food samples. High Pearson's correlation coefficients were found between hardness and fracturability ($r = 0.94$; $P < 0.0001$), hardness and gumminess ($r = 0.71$; $P < 0.0001$) and springiness and cohesiveness ($r = 0.85$; $P < 0.0001$). PCA identified two significant principal components, which accounted for 81.2% of the variance in the instrumental data. Additionally, a trained panel described the texture characteristics of the food samples according to the standard reference scales. The correlation curves showed nonlinear relationships (R^2 between 85.6% and 99.9%) which were used to predict sensory attributes of other food samples. Some texture attributes like hardness and fracturability were accurately predicted by mechanical properties, while others like cohesiveness and adhesiveness were less representative.

Keywords Principal component analysis, sensory evaluation, texture profile analysis.

Introduction

Texture is defined as the sensory manifestation of the structure of food and the way in which that structure reacts to the applied force (Meullenet *et al.*, 1997). It has also been described as a multiparameter attribute, as evidenced by the large number of terms used to describe it. The classification of texture attributes into categories introduced by Szczesniak *et al.* (1963) gave rise to a profiling method of texture description, the texture profile analysis (TPA) applicable to both sensory and instrumental measurements.

With the instrumental method, texture profiling involves compressing the test substance at least twice and quantifying the mechanical parameters from the force-deformation curves recorded. Although several instruments have been developed to measure multiple attributes of texture, they do not consider how well this information represents human perception. The Instron TPA double compression test has been shown, in many cases, to be closely associated with judgmental assessments of texture. Many studies in which this instrument was used generally agree on good-to-excellent correlations for hardness. Correlations for other parameters, however, are usually not so good (Szczesniak *et al.*, 1963; Meullenet *et al.*, 1997, 1998; Szczesniak, 2002). Because these correlations varied with the amount of mechanical deformation, sample dimensions and type of sensory panellists (consumers or trained assessors), further research should be directed towards the standardization of procedures for both sensory and instrumental testing.

With the sensory method, the evaluation includes several steps outside and inside the mouth, from the first bite through mastication, swallowing and residual feeling in the mouth and throat; its use is based on standard scales (Szczesniak *et al.*, 1963; Muñoz, 1986). The standard rating scales provide a method of correlating sensory (Brandt *et al.*, 1963) and instrumental (Szczesniak *et al.*, 1963; Bourne, 1978) evaluations of texture. Standard scales are developed to identify each of the mechanical characteristics of texture and provide a defined, quantitative method of texture evaluation (Szczesniak, 2002). The reference texture scales developed by Szczesniak *et al.* (1963) consist of foods used as descriptors of specific texture attributes. Szczesniak scales were evolving and were modified throughout the years by a number of researchers including Civille & Liska (1975), Szczesniak (1975) and Muñoz (1986). Chauvin *et al.* (2008) developed standard scales for

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crispness, crunchiness and crackliness for dry and wet foods providing individuals interested in auditory texture evaluation with a starting point to assist in training descriptive analysis of food texture. More recently, Chauvin *et al.* (2009) evaluated some standard scales determining whether the reference foods actually represent the attribute intensities originally published by Szczesniak *et al.* (1963). They verified that these scales still represent a highly standardised and well-defined reference system for training texture profile panels.

As the published standard rating scales that have been used so far are based on well-known foods, there is a need to develop standard rating scales based on foods familiar to the panellists to carry out an effective textural assessment of the food (Hough *et al.*, 1994; Otegbayo *et al.*, 2005). Additionally, the continuous growth of international food trade and common market promotes the use of unified terminology and reference scales for cross-border quality control and specifications of sensory properties (Hough *et al.*, 1994). Understanding the relationship between food texture perception and food structure is of increasing importance for companies wishing to produce texturally attractive food products (Wilkinson *et al.*, 2000). Cardello *et al.* (1982) and Muñoz (1986) reported some modifications of the original scales proposed by Szczesniak *et al.* (1963), whereas other authors have reported modifications of scales with regional foods. Bourne *et al.* (1975) modified the original scales with Colombian foods, whereas Anzaldua-Morales & Vernon (1984) reported a hardness reference scale for Mexican foods. However, in all of these cases, the instrumental–sensory relationships were not clearly specified. Meullenet *et al.* (1998) evaluated Szczesniak scales by studying texture relationships between sensory and instrumental TPA techniques to evaluate twenty-one food samples. They found relevant linear correlations for some parameters (hardness and springiness) and no significant correlations for other parameters (cohesiveness and chewiness). Di Monaco *et al.* (2008) studied sensory–instrumental relationships of three textural attributes (hardness, cohesiveness and springiness) with fifteen solid foods. Their study found that only sensory hardness was adequately predicted using a nonlinear relationship with TPA hardness (% R^2 87.5). Hough *et al.* (1994) constructed a complete set of thirteen reference scales with argentine foods. In their work, scores given by the trained panel using these reference scales were found to be similar to those given by a trained panel using the US scales in both direction and magnitude but they did not specify any relationship with instrumental measurements (Hough *et al.*, 1994).

The objectives of this study were to assess and validate the instrumental–sensory relationships of some texture scales (hardness, fracturability, adhesiveness, springiness, cohesiveness, gumminess and viscosity) using argentine foods as references of scales.

Materials and methods

Samples

Food samples used in this study have been previously described by Szczesniak *et al.* (1963) when developing the texture reference scales. For a given attribute, it was used argentine substitutes to the US standards representing different points on a scale. These argentine substitutes were developed by Hough *et al.* (1994). Modifications of brands and type were necessary in some instances owing to local availability following the recommendations given by Bourne (1982) regarding well-known brands, ease of preparation and small variations with temperature and/or storage. A total of thirty-seven food products were sized, prepared and tempered as recommended by these authors for evaluation by the instruments (Table 1). The scales chosen were hardness, fracturability, cohesiveness, adhesiveness to palate, springiness, gumminess and viscosity.

To validate sensory–instrumental correlations between hardness, fracturability, cohesiveness and adhesiveness to palate scales, additional food product samples that have not been previously used as references of scales were instrumentally tested and also evaluated by the trained sensory panel. These food products were purchased from well-known manufacturers and were selected because of a texture attribute that seemed to prevail.

Instrumental analysis

Food samples were instrumentally evaluated using an Instron universal testing machine (model 3345). The instrumental TPA test described by Bourne (1978) was used. A two-cycle compression was set for a 70% strain. A compression load cell (5000 N) interfaced with series data acquisition software (Bluehill 2 version 2.17; Instron, Norwood, MA, USA) was used to evaluate the stress applied to the samples during compression. The cross-head speed or loading rate was set to 0.001 m s^{-1} for the evaluation of all samples. Every test was replicated a minimum of ten times, and mean values for each parameter were calculated. Parameters corresponding to mechanical attributes were obtained from the instrumental curves (Table S1). The test was configured so that the TPA parameters, hardness, fracturability, adhesiveness to palate, cohesiveness, springiness and gumminess, were calculated at the time of the test by determining the load and displacement in predetermined points on the curve.

Viscosity measurements were taken using a Paar Physica rheometer (model MCR 300; Anton Paar GmbH, Graz, Austria). The tests were performed using a cone/plate sensor system (CP 25-2) with a gap width of 5.10^{-5} m. A thermostatic bath was used to control the working temperature at 24 °C according to the suggestion of Szczesniak (1963) who described the best

Table 1 List of food products and the correspondent sensory scale values used in modelization

Parameter	Product (size, temperature)	Brand or type-manufacturer	Scale value	References
Hardness	Cream cheese (1 cm^3, 5–10 °C)*	Casancrem – La Serenísima	1	Hough *et al.* (1994)
	Egg white (hard boiled 5 min; 0.75 cm^3, room)	–	2.5	
	Frankfurter (1 cm slice, room)	Vienisima – Tres Cruces	5	
	Olive (1 piece, room)	Stuffed, pepper removed – Nucete	6	
	Peanut (1 piece, room)	Unsalted – Kelloggs	9.5	
	Chocolate (1 cm^3, 10–15 °C)	Bittersweet – Suchard	11	
	Hard candy (1 piece, room)*	Menthoplus – Arcor	17	
Fracturability	Cake (1 cm^3, room)*	Withou fruit – Bagley	1	Hough *et al.* (1994)
	Biscuit layer (1 cm^2, room)	Fantoche	2.5	
	Cracker (1 cm^2, room)	Criollitas – Bagley	5	
	Biscuit (1 cm^2, room)	Melitas – Bagley	8	
	Thin bread wafer (1 cm^2, room)	Minitost – Maxim S.A.	10	
	Peppermint (1 piece, room)	DRF-Bonafide	12	
	Hard candy (1 piece, room)*	Menthoplus – Arcor	14.5	
Viscosity	Water (1/2 teaspoon, room)*	Villa del Sur	1	Adapted from Szczesniak *et al.* (1963)
	Light cream (1/2 teaspoon, 5–10 °C)	Sancor	2	
	Heavy cream (1/2 teaspoon, 5–10 °C)	Sancor	3	
	Chocolate syrup (1/2 teaspoon, 5–10 °C)	La Parmesana – American spices	6	
	Mixture: 1/2 cup mayonnaise + 2 tbs heavy cream (1/2 teaspoon, 5–10 °C)	Hellman's + Sancor	7	
	Sweetened condensed milk (1/2 teaspoon, 5–10 °C)*	La lechera – Nestle	8	
Cohesiveness	Cake (1 cm^3, room)*	Without fruit – Bagley	1	Hough *et al.* (1994)
	Processed cheese (1 cm^3, 5–10 °C)	Pategras – Sancor	5	
	Fruit chew (1 cm^3, room)	Frutifru – Arcor	8	
	Dried fruit (1 piece, room)	Raisins – Sultanita – Morena	8.2	
	Jelly candy (1 piece, room)	Mogul – Arcor	11.5	
	Fruit chew (1/2 piece, room)*	Sugus – Suchard	12	
Gumminess	40% flour paste (1 tbs, room)*	Favorita – Molinos Río de la Plata	1	Adapted from Szczesniak *et al.* (1963)
	45% flour paste (1 tbs, room)		2	
	50% flour paste (1 tbs, room)		3	
	55% flour paste (1 tbs, room)		4	
	60% flour paste (1 tbs, room)*		5	
Adhesiveness to palate	Margarine (1 cm^3, 5–10 °C)*	La Delicia – Molinos Río de la Plata	1	Hough *et al.* (1994)
	Peach jam (1/2 teaspoon, room)	Arcor	3	
	Milk jam recipe (1/2 teaspoon, 5–10 °C)	For cakes – La Serenisima	6	
	Spreading cheese (1/2 teaspoon, 5–10 °C)	Tholem-Sancor	7.5	
	Peanut butter (1/2 teaspoon, room)*	Skippy Smooth – Best Foods	12	
Springiness	Cream cheese (1 cm^3, 5–10 °C)*	Casamcrem-La Serenísima	0	Hough *et al.* (1994)
	Jelly candy (1 piece, room)	Mogul – Arcor	5.2	
	Biscuit filling (1 piece, room)	Merengada – Bagley	6.5	
	Gelatin dessert[†] (1 cm^3, 5–10 °C)	Exquisita – Molinos Río de la Plata	11	
	Gelatin dessert[‡] (1 cm^3, 5–10 °C)*	Exquisita – Molinos Río de la Plata	15	

*Extreme of scale.

[†] 7 g of unflavored gelatin + 85 g of strawberry gelatin, dissolving in 375 mL of boiling water, refrigerated immediately.

[‡] 85 g of unflavored gelatin + 85 g of strawberry gelatin, dissolving in 375 mL of boiling water, refrigerated immediately.

sensory/instrumental correlation when studies were performed at this temperature. The shear rate was set varying from 0 to 1.83 s^{-1} (110 rpm). Five replications were measured for each sample. Samples were maintained at rest for 20 min in the sensor unit before measurements to ensure uniform temperature and reduce immediate effects owing to sample manipulation. Flow curves (viscosity per shear rate) were automatically recorded. Results were reported as the average of the viscosity obtained at 1.66 s^{-1} (100 rpm) recommended by Szczesniak *et al.* (1963).

Sensory analysis

The sensory panel was composed of nine panellists (three men and six women), aged 21–38. For the selection of panellists, twenty people were recruited from the staff of Buenos Aires University based on their interest, availability, previous experience in sensory evaluation and familiarity in texture concepts or terminology. During the prescreening procedure, the panellists were evaluated for normal sensory acuity through a basic taste test, a sequential triangle test (Meilgaard *et al*., 1999) and an intensity ranking test using the hardness scale (Civille & Szczesniak, 1973). The panellists who passed the prescreening tests were further trained with the texture profile method, following the procedures described by Civille & Szczesniak (1973) for 35–40 h (2 h per week) to recognise texture attributes of hardness, fracturability, cohesiveness and adhesiveness to palate. The first sessions of training were devoted to explaining definitions of texture (Table S1) and familiarising the panellists with the sensory texture profile method and some reference food products corresponding to standard rating scales published by Hough *et al*. (1994) and by Szczesniak *et al*. (1963). The use of the standard rating scales was explained using one scale per session. Each standard rating scale was worked on until the panellists fully understood the texture concepts and properly matched each food reference product with its correspondent value in the scale. Round-table discussions were then performed to clarify any possible large discrepancies so as to reach a general consensus between the panellists. Each scale food reference was periodically refreshed to calibrate the sensory panel. For the instrumental–sensory correlation, sensory data corresponding to the standard food references were obtained from the study by Szczesniak *et al*. (1963) and Hough *et al*. (1994). The trained panel either confirmed these values or defined new sensory ratings by consensus when food substitutes were used.

Additional food samples used to externally validate the sensory–instrumental relationships of hardness, fracturability, adhesiveness to palate and cohesiveness scales were measured by the trained panel. On each session, samples were presented to the panellists in white plastic cups coded with random three-digit numbers. Two known food references and the evaluation form were also provided with the sample. This form included instructions and the line scale corresponding to the texture attribute with the positions of the references indicated on it. A glass of water and unsalted crackers were used for rinsing their mouth and cleaning their teeth between sample evaluations. Starting each session, panellists were thoroughly refreshed with the definitions and techniques for measuring texture attributes in which they had been trained earlier. They used evaluation forms and scored intensities on the line scale (0–17, depending on the texture scale). Judging was done individually. Three replications of each sample were evaluated in different sessions. All sessions were conducted in booths under white light and in an environment-controlled sensory analysis laboratory.

Statistical analysis

The instrumental TPA information was analysed by multivariate analysis of variance (MANOVA) (Quinn & Keough, 2002). *Post hoc* multiple comparisons among multivariate means of samples were made by Hotelling tests based on Bonferroni correction. Pearson's correlation coefficients were calculated between instrumental response variables (hardness, fracturability, cohesiveness, adhesiveness, springiness and gumminess), and principal component analysis (PCA) of mean ratings for each attribute was used as an extension of MANOVA (Mcgarigal *et al*., 2000) to illustrate the relationship between response variables and samples. Previously, to conduct the analyses, the assumptions of homogeneity of variance/covariance matrices and multivariate normal distribution were tested. Viscosity and sensory data were analysed by the analysis of variance (ANOVA) to establish the presence or absence of significant differences between samples or panelists. Significance level was set at $\alpha < 0.05$ WHITH establish if significant differences ($p < 0.05$) exist between samples and panelists. Turkey's test was performed when significant differences were found.

Nonlinear regression models were evaluated to assess the instrumental–sensory relationships. Models were internally validated to determine whether they could adequately describe the experimental data by means of ANOVA, the coefficient of determination, R^2 and the Fisher test. Also they were externally validated by instrumental and sensory measures of other eight food products. The best equations obtained in the correlation study were used to predict the sensory responses from the instrumental measurements. Predicted sensory values were compared with the sensory measured ones by using the Student's *t*-test. To reduce panel sessions models describing sensory–instrumental correlations for springiness, viscosity and gumminess scales were not externally validated. All regression analyses were applied using Statgraphics Plus (Statistical Graphics Corp., Washington, DC, USA) and InfoStat (InfoStat Group, Córdoba, Argentina).

Results and discussion

Analysis of instrumental data

Tables 2 and 3 shows the means and standard deviation of the instrumental texture parameters derived from the TPA (Table 2) and viscosity–shear rate curves (Table 3) determined for the different food samples. The selected food samples that spanned almost the entire range of sensory texture scales covered a wide range of instrumental values too. The one-way MANOVA of TPA measurements was highly significant ($F_{180,\ 1842} = 23.23$; $P < 0.0001$). Sample centroids were statistically different as the result of *post hoc* multiple comparisons

Table 2 Instrumental values and standard deviations for reference food products determined with texture profile analysis

Hardness (N)	
Cream cheese (CC)	2.7 ± 0.1
Egg white (EW)	7.7 ± 1.5
Frankfurter (F)	66.2 ± 4.4
Olive (O)	75.7 ± 18.9
Peanut (P)	267.5 ± 55.6
Chocolate (CHOC)	539.0 ± 76.5
Hard candy (HC)	1330 ± 180
Fracturability (N)	
Cake (C)	0
Biscuit layer (BL)	19.4 ± 2.9
Cracker (C1)	35.8 ± 9.9
Biscuit (B)	65.1 ± 7.2
Thin bread wafer (TB)	261.9 ± 57.2
Peppermint (PP)	718.7 ± 61.4
Hard candy (HC)	1164 ± 269
Cohesiveness (–)	
Cake (C)	0.23 ± 0.02
Processed cheese (PC)	0.24 ± 0.04
Fruit chew (FC)	0.08 ± 0.02*
Dried fruit (DF)	0.34 ± 0.03
Jelly candy (JC)	0.78 ± 0.02
Fruit chew (FCS)	0.13 ± 0.03*
Gumminess (N)	
40% flour paste (40%)	0.50 ± 0.05
45% flour paste (45%)	1.6 ± 0.4
50% flour paste (50%)	3.1 ± 1.2
55% flour paste (55%)	6.3 ± 1.9
60% flour paste (60%)	13.4 ± 1.7
Adhesiveness to palate (J)	
Margarine (M)	0.007 ± 0.002*
Peach jam (PJ)	0.0028 ± 0.0006
Milk jam recipe (MJR)	0.010 ± 0.002
Spreading cheese (SC)	0.011 ± 0.001
Peanut butter (PB)	0.015 ± 0.003
Springiness (–)	
Cream cheese (CC)	0.5 ± 0.1
Jelly candy (JC)	0.78 ± 0.02
Biscuit filling (BF)	0.79 ± 0.01
Gelatin dessert 1 (G1)	0.88 ± 0.04
Gelatin dessert 2 (G2)	0.96 ± 0.01

Units: N, Newton; J, Joule.

*This point was not considered for the sensory-instrumental correlation.

Table 3 Viscosity of reference food products determined with a cone/plate sensor system

Viscosity (cP)	
Water	3.74 ± 0.84
Light cream	147 ± 8
Heavy cream	25.8 ± 16
Chocolate syrup	506 ± 9
Mixture: 1/2 cup mayonnaise + 2 tbs heavy cream	1254 ± 38
Condensed milk	2688 ± 48

Unit: cP, centiPoise.

(Hotelling tests $P < 0.05$), although the following multivariate means did not differ statistically: milk jam recipe (MJR) – 45% flour paste (45%) and peach jam (PJ) – cracker (C1).

Pearson's correlation coefficients between the instrumental parameters were calculated (Table S2). Hardness was highly correlated with fracturability ($r = 0.94$, $P < 0.0001$). In general, as the hardness of samples increased, so did their fracturability. The samples with high hardness value had low cohesiveness (not deformed). A significant correlation was found between springiness and cohesiveness ($r = 0.85$, $P < 0.0001$). The instrumental measurements of cohesiveness (A_2/A_1) were highly dependent on the springiness of the samples. For example, chew candies, which had very little instrumental springiness (data not shown), exhibited very low cohesiveness because of the scarce contact with the sample during the second bite. Therefore, the second peak area would be negligible. This behaviour was in agreement with that reported by Meullenet *et al.* (1997).

Instrumental gumminess was obtained by multiplying the values for hardness and cohesiveness. The correlation between gumminess and hardness was highly significant ($r = 0.71$, $P < 0.0001$) and very poor with cohesiveness ($r = 0.06$, $P = 0.762$). The fact that the physical measurement A_2/A_1 was not a good evaluation of cohesiveness in some food samples could explain the poor observed correlation.

A multivariate approach to instrumental data analysis by PCA showed the spatial relationships of the six instrumental texture attributes derived from the same texture profile curve (fracturability, hardness, cohesiveness, gumminess, springiness and adhesiveness to palate) for each food sample. Viscosity attribute was not considered in this analysis because it was not derived from TPA test. A two-dimensional representation of this analysis is presented in Fig. 1. The first two principal components explained 52% and 29.2% of the variance, respectively, in the PCA of the instrumental data. The first contrasted hardness and fracturability (positively) with springiness, adhesiveness to palate and cohesiveness (negatively). The second axis was defined positively by gumminess and springiness.

Products such as hard candy and peppermint were very close to the hardness and fracturability attributes. This showed that these samples have two dominant properties (hardness and fracturability). Samples were placed to the right and in the higher half of the graph. Chocolate (CHOC), thin bread, olive (O), biscuit (B), crackers (C and C1), biscuit layer (BL), fruit chew candy and peanut (P) were placed to the right and in the lower half of the graph. These products not have a dominant characteristic but they lacked springiness, adhesiveness to palate and cohesiveness. PJ, frankfurter (F), cream cheese (CC), dried fruit, margarine (M), egg white, flour pastes (40%, 45%, 50%, 55% and 60%), gelatin dessert

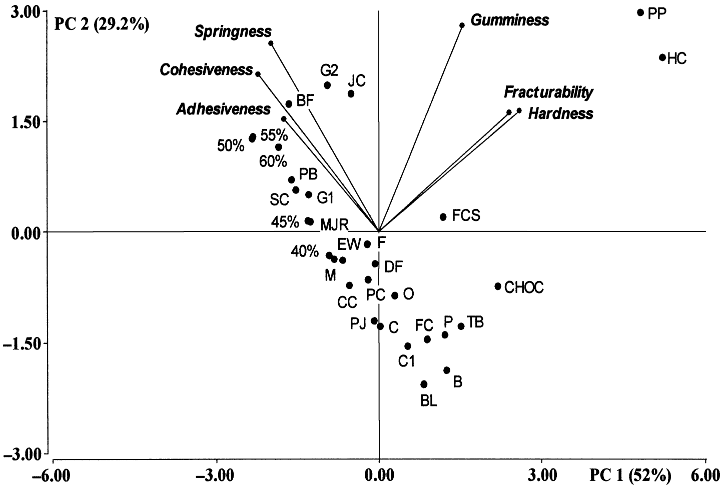

Figure 1 Principal component analysis of instrumental measurement food samples. Labels of food samples are referenced in Table 4.

(G1), MJR, biscuit filling (BF), peanut butter and processed cheese were placed to the left of the graph. The analysis showed that these food products do not have a single dominant characteristic but, in fact, exhibited at least three primary characteristics (springiness, adhesiveness to palate and cohesiveness) and lacked fracturability. Gelatin dessert (G2) and jelly candy showed two dominant properties (springiness and gumminess). Samples were placed to the left and in the higher half of the graph.

Analysis of viscosity data showed significant differences ($F_{5,23}$ = 6258, $P < 0.0001$) between all evaluated food samples chosen for representing the viscosity scale (Tukey's test HSD = 57.2 $P < 0.05$).

Correlation between sensory attributes and instrumental parameters

Figure 2 shows the correlations between sensory scores and instrumental measurements corresponding to the different texture scales. As it can be observed, they were, in general, well correlated. The correlation curves obtained for the different scales showed nonlinear relationships. Except for adhesiveness, they were similar in shape, with an upward concavity, indicating that samples with low objective values could be better discriminated by the panel than instrumentally. These correlations were well described by the following exponential relationship:

$$y = a \cdot \mathrm{e}^{b \cdot x} \tag{1}$$

while adhesiveness to palate instrumental–sensory correlation exhibited a downward concavity and was adequately described by the following relationship

$$y = a \ln(x) - b \tag{2}$$

where y: instrumental measurement; x: sensory score and a,b: parameters.

Controversy in the literature exists regarding the relationship between sensory and instrumental data. When evaluating standard texture scales, Meullenet *et al.* (1998) observed that correlation coefficients between sensory and instrumental data were improved through the use of logarithmic transformation. Yuan & Chang (2006) correlated TPA hardness and springiness of tofu with sensory parameters and found linear instrumental and sensory correlations, whereas Szczesniak *et al.* (1963) reported a nonlinear relationship between sensory hardness ratings and texturometer hardness values when evaluating standard scales. The nonlinear relationship could be attributed to a distortion of the physical stimulus by the sensory system or loss of sensitivity as its intensity increases. The use of sensory scores surged from 15-cm unstructured scales may introduce additional distortion (Cardello *et al.*, 1982; Meullenet *et al.*, 1998).

Table 4 summarises parameter coefficients corresponding to the models for the different texture scales. Determination coefficients indicated that between 86% and 99% of variability in instrumental–sensory hardness, fracturability, viscosity, cohesiveness and gumminess values could be explained by the eqn 1. In the case of adhesiveness to palate attribute, the variability explained by the eqn 2 was 89%.

In cohesiveness and adhesiveness to palate scales, some sensory ratings assigned to food samples did not correlate with the instrumental measurements and were not considered in the models. In the cohesiveness scale, only four food reference products were used to determine the instrumental–sensory correlation because in samples like chew candies (no elastic), instrumental measurements were very low. A cohesive sample that exhibits little or no springiness (such as caramels) will have very low values for A_2/A_1 because there will be very little contact with the sample during the second compression. Meullenet *et al.* (1997, 1998) reported that

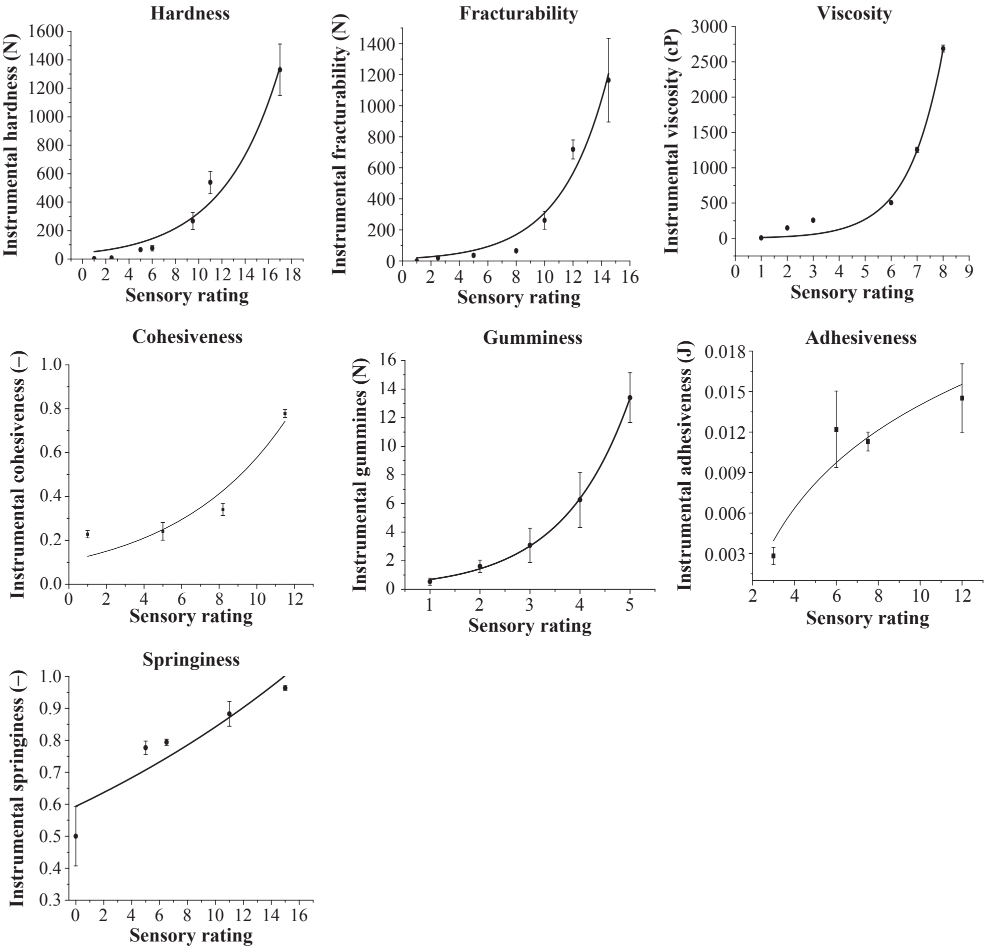

Figure 2 Instrumental–sensory correlations with texture parameters. (•) experimental data; (—) model prediction; (I) error bar.

Table 4 Estimated model coefficients corresponding to the texture scale instrumental-sensory relationships

	a	b	Variability explained R^2 (%)	Fisher[†]
Model[‡]: $y = a{\cdot}e^{b.x}$				
Texture scales				
Hardness	42.2 ± 14.9	0.21 ± 0.02	97.5	152.3***
Fracturability	15.2 ± 8.6	0.33 ± 0.04	96.7	120.4***
Viscosity	5.9 ± 3.6	0.77 ± 0.08	98.8	303.2***
Cohesiveness	0.11 ± 0.05	0.17 ± 0.04	90.6	42.9**
Gumminess	0.33 ± 0.02	0.74 ± 0.02	99.9	5495.7***
Springiness	0.59 ± 0.05	0.03 ± 0.01	85.6	269.6***
Model[‡]: $y = a \ln(x) - b$				
Adhesiveness to palate	0.0084 ± 0.0021	0.0052 ± 0.0039	89.2	57.7**

[†] Significant at **5% level, ***1% level.

[‡] y, Instrumental measure; x, sensory score.

the evaluation of the A_2/A_1 ratio was dependent on the evaluation of d_2/d_1 ratio (i.e. springiness of the product) and the poor correlation between instrumental and sensory cohesiveness to samples without springiness. Lyon *et al.* (1980) also reported poor correlations between the sensory and instrumental assessments of cohesiveness when evaluating poultry patties (no elastic). Description of sensory perception of cohesiveness may not be well characterised by one physical measurement (A_2/A_1) when comparing food samples from different food systems, but could be a good indicator in a limited group of foods such as gels (Meullenet *et al.*, 1998). Di Monaco *et al.* (2008) found a nonlinear relationship between sensory and instrumental measurements of hardness, whereas cohesiveness and springiness were poorly predicted.

In the adhesiveness scale, the instrumental measurement of one food reference product (margarine) did not adequately correlate with the sensory rating being significantly greater. Preliminary research showed that the texture of this type of food is affected by small changes in temperature. Szczesniak *et al.* (1963) commented that the food items selected for the development of standard rating scales had to meet the requirement of a minimum change in textural properties from small temperature variations. Chauvin *et al.* (2009) reported an inconsistency in the standard adhesiveness scale where some reference foods were not well perceived. The discrepancy was attributed to taste preference and inability of the panel to hold the food inside their mouths for a required amount of time.

Validation of the sensory–instrumental correlations

For sensory measurements, food references selected to represent hardness, fracturability, adhesiveness, springiness, cohesiveness, gumminess and viscosity scales were well identified by the panellists according to Table 1 during the training period and were well assigned to the corresponding scale under the successive sessions. These results indicate that the panel acquired a good degree of training and was able to quantitatively evaluate the individual mechanical parameters of texture.

Table 5 lists the additional food samples used to externally validate the sensory–instrumental relationships of hardness, fracturability, adhesiveness to palate and cohesiveness scales. Additionally, Table 5 shows the means and the standard deviations of the sensory ratings assigned by the panellists, the instrumental measurements and the predicted sensory values according to the eqns 1 and 2. There were no significant differences among panellists (Tukey's test $P < 0.05$) for the texture parameters evaluated, thus showing consistency (data are not shown). Student's t-test comparisons between observed and predicted sensory values showed that the proposed models used in this study adequately predict sensory attributes of the new food samples from instrumental measurements because all P-values were not statistically significant at $\alpha = 0.05$. Additionally, the locally available standards of the scales used undoubtedly contributed to a good correlation. In general, adhesiveness to palate and cohesiveness sensory predictions exhibited larger confidence intervals being less representative. This may be because of the fact that the instrumental methods used to measure these mechanical attributes do not break the samples, whereas the sensory evaluation technique of these textural attributes concerns the rupture of the samples.

Conclusions

Some standard reference scales used in texture profiling were instrumentally and sensory checked using or adapting available standards defined for countries

Table 5 Means and standard deviations of sensory and instrumental measurements and predicted sensory score of food samples

Product (size, temperature)	Type/brand-manufacturer	Instrumental value	Predicted[†] sensory value	Observed[‡] sensory value	*P* value[§]
Hardness (N)					
Biscuit (1 cm^2 *cube, room)*	Manon – Terrabusi	223.1 ± 60.8	7.6 ± 1.3	7.96 ± 0.65	0.697*
Fresh apple (slice 3 cm, 1 cm, 5–10 °C)	Granny Smith	293.2 ± 30.3	8.8 ± 1.1	7.82 ± 0.97	0.307*
Blanching apple (slice 3 cm, 1 cm, 5–10 °C)	Granny Smith – 90s in steam	196.2 ± 24.5	6.99 ± 1.25	6.56 ± 0.69	0.638*
Fracturability (N)					
Biscuit (1 cm^2*, room)*	Manon – Terrabusi	223.1 ± 60.8	8.1 ± 1.8	7.2 ± 1.7	0.563*
Hard candy (1 piece, room)	La Yapa – Stani	1007 ± 233	12.7 ± 2.3	12.7 ± 2.7	0.990*
Adhesiveness to palate (J)					
Cream cheese (1/2 teaspoon, 5–10 °C)	Mendicrim – Nestlé	0.0045 ± 0.0009	3.2 ± 2.6	4.4 ± 0.5	0.515*
Milk jam recipe (1/2 teaspoon, 5–10 °C)	Classic – Sancor	0.0042 ± 0.0001	3.1 ± 2.6	5.1 ± 0.9	0.335*
Cohesiveness (–)					
Jelly candy (1 piece, room)	Fruit ring Mogul – Arcor	0.75 ± 0.02	11.3 ± 2.7	10.2 ± 1.5	0.581*

*Value non statistically significant at $\alpha = 0.05$.

[†] Predicted sensory value obtained from eqns 1 or 2 and the correspondent instrumental value.

[‡] Observed sensory value obtained with the trained panel.

[§] *P*-value corresponding to the comparison of sensory values using Student's *t*-test.

outside United States. Useful nonlinear correlations were found between corresponding objective parameters and sensory scores to texture attributes of the food reference samples. The instrumental TPA can measure the same intensity of textural characteristics as perceived of food samples selected to check the instrumental–sensory correlations that were adequately predicted by the proposed models. However, some problems were found with the measurement of cohesiveness in slightly elastic samples and with the measurement of adhesiveness in samples sensitive to small variations in temperature. An instrumental measurement of cohesiveness producing reliable results independently of food sample's springiness needs to be developed.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Instrumental and sensory definitions used for texture attributes.

Table S2. Pearson's correlation coefficients between instrumental parameters.