Eur Food Res Technol (2009) 229:21–30
DOI 10.1007/s00217-009-1022-3

ORIGINAL PAPER

Bread crumb quality assessment: a plural physical approach

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Received: 26 November 2008 / Revised: 13 January 2009 / Accepted: 17 January 2009 / Published online: 11 February 2009

Abstract The aim of this study was the assessment of pan bread crumb quality attributes of commercial samples using a plural physical approach to better match consumer awareness. Static (texture profile analysis, firmness AACC and relaxation test) and dynamic (innovative oscillatory test) deformation techniques, image analysis, sensory analysis and colour measurements (colorimeter and Photoshop system) were used for white/whole commercial pan bread quality evaluation over 10 days of storage. Static (k_1, k_2, cohesiveness, springiness, hardness, chewiness and resilience) and dynamic (stress) bread crumb rheological properties were correlated illustrating that both techniques can be useful in evaluating crumb physical characteristics. In addition, sensory perceiveness with regard to softness and overall acceptability exhibited dependence with either dynamic stress or static firmness. Despite the fact that empirical measurements are closely linked to macroscopic features whilst dynamic tests are strongly linked to molecular characteristics, the obtained results support that both techniques are complementary since derived instrumental parameters are related to some sensory attributes. As data achieved using the proposed novel approaches might be better linked to the consumer awareness than those obtained from classical analyses, the obtained results are promising for a proper bread crumb quality assessment.

Keywords Pan bread · Colour measurement · Texture · Crumb structure · Staling · Sensory evaluation

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Introduction

Textural attributes are key characteristics that consumers appreciate in pan bread. Crumb freshness is associated with its specific structure and, especially with the mechanical properties of the cell walls that form the air cells in bread [1–3]. An essential food consumed worldwide—bread—rapidly loses its desirable texture and flavour qualities associated with freshness. When stored at room temperature, most breads or bakery products with a spongy crumb undergo a progressive and often rapid deterioration of quality, commonly known as staling [4, 5], particularly in high-moisture samples.

Many instrumental methods are used to measure mechanical properties of baked goods that are, up to a certain extent, related to sensory characteristics [6]. Crumb hardness is often used as a measure of bread staling, which has been successfully determined using a texture analyser in a static compression mode [4, 7]. A standard method [8] for bread staling based on force-deformation for firmness in the static compression mode is available. Relaxation experiments provided data related to bread crumb mechanical changes associated to staling process [9]. Results obtained with traditional instruments are strongly dependent on experimental conditions and limited to empirical correlations and thus, these tests do not provide fundamental rheological data.

Bread crumb is a solid-like material that does not exhibit a proportional stress to a given strain out of its linear viscoelastic region. Small strain methods, specifically dynamic oscillatory shear and mechanical analyses, are useful in probing microstructure, viscoelastic properties and phase transitions in food materials. Dynamic mechanical and thermal mechanical analysis used to determine dynamic rheological properties of polymeric material including foams have also been successfully used for textural characterisation of bakery products [10–12]. This analysis solves the limitations of a shear rheometer employed on solid materials by operating in an oscillatory compressive mode [13]. An innovative dynamic oscillatory test performed using a TA-XTplus Texture Analyser (Stable Micro System, Godalming, Surrey, UK) is a promising tool to explore fresh and aged bread crumb mechanical attributes on a fundamental basis.

Fresh and aged bread crumb mechanical properties are often connected to sensory perception of freshness and elasticity by consumers [14] and also largely influence subsequent purchase. However, sensory evaluation is not often used in baking industry mainly because of both time and cost of a sensory panel training and managing. Fresh bread is a product with a short shelf-life, and during storage, chemical and physical alterations occur. Staling mainly results in textural changes to bread, and many methods are available for characterizing bread staling with respect to its mechanical properties. Traditional mimetic methods, such as texture profile analysis, firmness, stress relaxation, penetration and compression tests provide useful and well-recognised information about bread crumb mechanical properties [2, 3, 6, 7, 9, 12, 15]. However, data obtained from the above-cited measurements are subjected to a large variability depending on the experimental followed analysis procedures. For that reason, it is really difficult to compare the results from many of the published reports obtained with different instruments and procedures.

Food colour surface has proven to be decisive in food product acceptance by consumer, at first glance. Colour surface is the first sensation that consumers perceive and use as a tool to accept or reject food [16]. Colorimeter is largely used for colour evaluation, nevertheless it measures L^*, a^*, b^* coordinates only over a very few square centimetres, and thus, its measurement is not representative in heterogeneous food items such as bread crumb and crust [17]. Surface to be measured is often not uniform and always rather small (≈ 2 cm^2) when read using commercial colorimeters making the obtained data unrepresentative and difficulting/hindering the global analysis of the food surface [17, 18]. Many points of a representative area must be measured to obtain a proper colour profile.

This study aimed at assessing bread crumb quality attributes using a plural physical approach to better match consumer awareness. Static (texture profile analysis, firmness AACC and relaxation test) and dynamic (innovative oscillatory test) deformation techniques, image analysis, sensory analysis and colour measurements (colorimeter and Photoshop system) were used for white/whole commercial pan bread quality evaluation over 10 days of storage. Avrami non-linear regression equation was chosen as an useful mathematical model to properly study bread crumb firming kinetics.

Materials and methods

Materials

Six different commercial whole (I1, I2, I3) and white (B1, B2, B3) pan breads were tested. Bread formulations were retrieved from the labels of commercial samples. Whole sample formulations were: whole-wheat flour, water, yeast, sunflower oil, salt, sugar, dairy solids, emulsifiers (E-472e, E-471, E-481), preserving agents (E-281, E-202), acidity regulator (E-270), malt flour for I1; whole-wheat flour, water, yeast, vegetable oil, sugar, salt, malt flour, dietary fibre (inulin), gluten, emulsifiers (E-471, E-481), lactoserum, preserving agents (E-200, E-282), vinegar, stabiliser (E-412) for I2; whole-wheat flour, water, yeast, sugar, vegetable oil, salt, dietary fibre (inulin), emulsifiers (E-472e, E-471, E-481, E-472c), vinegar, bean flour, malt flour, preserving agents (E-200, E-282), antioxidants (E-307, E-304) for I3. White sample formulations were: wheat flour, water, yeast, sunflower oil, salt, sugar, dairy solids, emulsifiers (E-472e, E-471, E-481), preserving agents (E-281, E-202), acidity regulator (E-270), malt flour for B1; wheat flour, water, sugar, yeast, vegetable oil, wheat germ (1.2%), salt, bean flour, emulsifiers (E-471, E-481), preserving agents (E-200, E-282), vinegar, stabiliser (E-412) for B2; wheat flour, water, yeast, sugar, vegetable oil, salt, emulsifiers (E-472e, E-471, E-481), vinegar, preserving agents (E-200, E-282), acidity regulator (E-341), bean flour for B3. Nutritional information on commercial pan breads is reported in Table 1. Samples were stored at room temperature for 0, 1, 3, 6, 8 and 10 days before analysis.

Rheological measurements

Texture profile analysis

Bread primary and secondary mechanical characteristics (texture profile analysis in a double compression cycle) were recorded in a TA-XTplus Texture Analyser (Stable Micro System, Godalming, Surrey, UK) using a 25-mm diameter probe, 5-kg load cell, 50% penetration depth and a 30-s gap between compressions, on 20-mm thick slices. For textural measurements, three slices of two breads were used for each commercial sample at different storage periods. The obtained firming curves were modelled using the Avrami equation, and model factors were estimated by fitting experimental data into the non-linear regression equation $\theta = \frac{T_\infty - T_t}{T_\infty - T_0} = e^{-kt^n}$ [7], where θ is the fraction of

Table 1 Commercial pan bread nutritional information (approximate average values per 100 g of product)

	I1	I2	I3	B1	B2	B3
Energy value (kcal)	251	250	209	255	260	232
Proteins (g)	9	10	8.5	9	9	7.9
Carbohydrates (g) of which	47	39	38.9	48	47	42.9
Sugars (g)	4	3.8	2.3	4	6	4.3
Polyalcohols (mg)	Traces	–	–	Traces	–	–
Starch (g)	43	–	36.5	44	–	38.6
Fats (g) of which	3	6	2.2	3	4	3.2
Saturated (g)	0.5	1	0.3	0.5	2	0.4
Monounsaturated (g)	0.6	1.7	0.6	0.6	1.5	0.8
Polyunsaturated (g)	1	3.2	1.3	1.9	0.7	2
Cholesterol (mg)	Traces	–		Traces	<1	<5
Dietary fibres (g) of which	8	7.2	7.5	2	4	2.5
Soluble (g)		2.4	4.3	–	–	–
Insoluble (g)		4.8	–	–	–	–
Sodium (mg)	60	49	41	06	41	52
Calcium (mg)	–	–	–	–	–	137.8

See bread formulation in Sect. "Materials and methods"

the recrystallisation still to occur; T_0, T_∞ and T_t are crumb firmness at time 0, ∞ and time "t", respectively, k is a rate constant and n is the Avrami exponent.

Relaxation test

Samples from the centre of the crumb slices were cut into cylinders (25 mm diameter × 20 mm thick) and compressed using TA-XTplus Texture Analyser (Stable Micro System, Godalming, Surrey, UK). For their compression, a cylindrical upper die of 50 mm diameter was used at a cross speed of 0.5 mm/s. The strain used was 20% and the whole relaxation experiment lasted for 10 min. The obtained stress relaxation curves were normalised and linearised according to the Peleg [19], and Peleg and Pollak [20] model, previously applied by Singh et al. [21] for dough and by Mandala et al. [9] for bread.

$$\frac{F_0 t}{F_0 - F(t)} = k_1 + k_2 t$$

where F_0 is the initial force, $F(t)$ is the momentary force at time (t) and $k_1(s)$, k_2 are constants related to stress decay rate and residual stress at the end of the experiment, respectively. For each relaxation measurement, three samples were used.

Firmness

Bread firmness was measured following the AACC (74-09) standard method in TA-XTplus Texture Analyser (Stable Micro System, Godalming, Surrey, UK) using a 36-mm diameter probe, 5-kg load cell on 20-mm thick slices. For each firmness measurement, three samples were used.

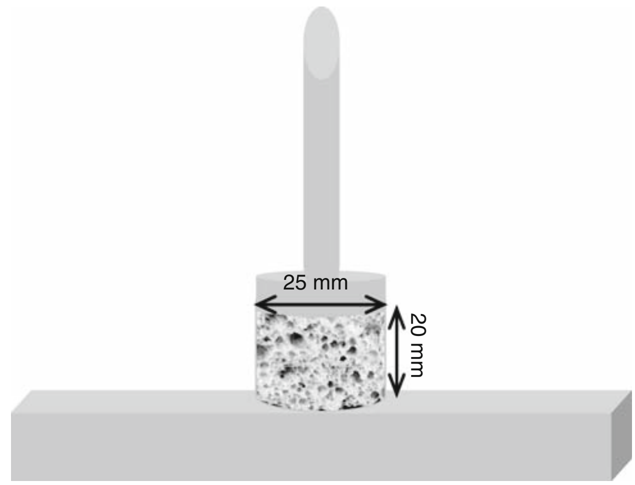

Fig. 1 Bread crumb sample for dynamic mechanical analysis in a TA-XTplus Texture Analyser

Dynamic test

A TA-XTplus Texture Analyser (Stable Micro System, Godalming, Surrey, UK) with an upper 25-mm parallel plate geometry and 20 mm gap was used for dynamic mechanical analysis, and stress was recorded and plotted as a function of frequency. Cylindrical crumb samples (25 mm diameter × 20 mm thick) were cut from the centre of each slice using a circular cutter and then placed between the parallel plates at room temperature (Fig. 1). Linear viscoelastic region was determined by performing a stress versus strain test (Fig. 2). Dynamic strain (sinusoidal) of 0.04% (within the linear viscoelastic region) was applied in the compression mode at different frequencies from 0.1 to10 Hz.

Fig. 2 Strain dependence of stress profiles for commercial pan bread samples (frequency 1 Hz)

Colour measurements

Colour determinations were carried out on crumb either using a Minolta Colorimeter (Minolta Co., Osaka, Japan) or a Photoshop system, and the results were expressed in accordance to the Hunter Lab colour space. The colorimeter was calibrated before each analysis with white and black standard tiles. Crumb colour was determined on five points on the central slices. The parameters determined were L [$L = 0$ (black) and $L = 100$ (white)], a ($-a =$ greenness and $+a =$ redness) and b ($-b =$ blueness and $+b =$ yellowness). The Photoshop system (L, a, b colour coordinates) was calibrated (Fig. 3) using colour sheets from Pantone® Formula Guide (Pantone, Inc., USA). Pantone colour sheets (for calibration) and bread slices (for colour measurement) images were acquired at 300 pixel resolution with a ScanJet II cx flatbed scanner (Hewlett-Packard, USA). The scanner was held in a black box in order to exclude the surrounding light. All measurements (three slices per sample) were made in triplicate.

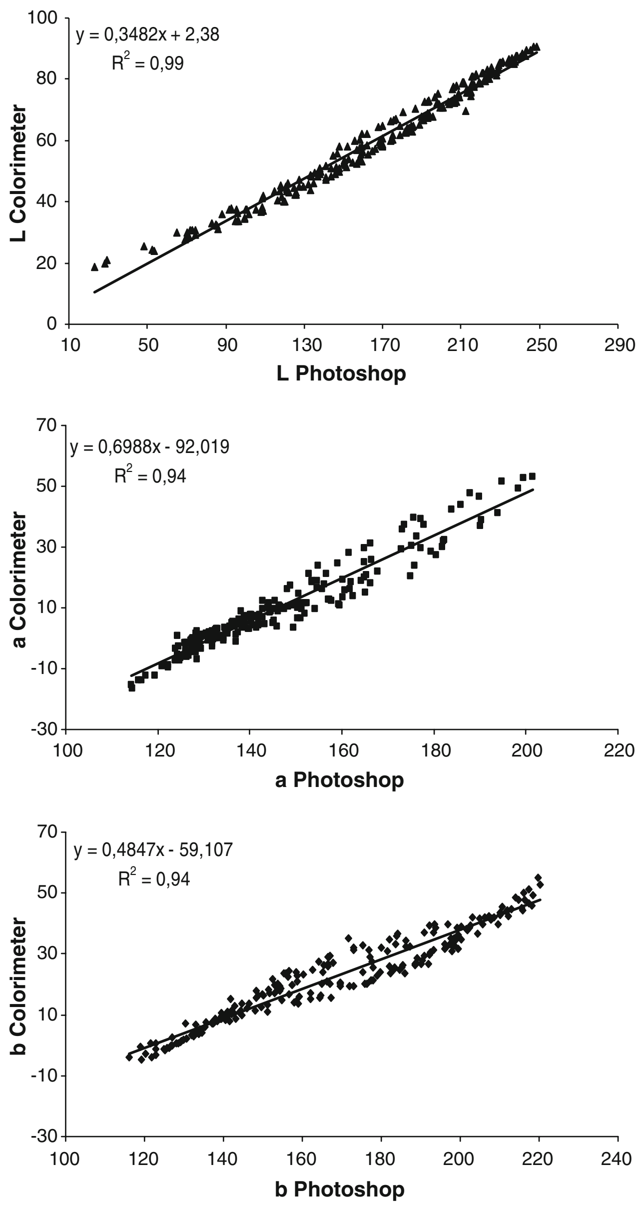

Fig. 3 Photoshop and colorimeter response by of the Pantone® colour sheets

Crumb grain characteristics

Crumb grain characteristics of the loaves were assessed using a digital image analysis system. Images were previously acquired with a ScanJet II cx flatbed scanner (Hewlett-Packard, USA) supporting a Deskscan II software. The analysis was performed on 55 mm × 55 mm taken from the centre of the image. Data were processed using SigmaScan Pro 5 software (Jandel Corporation, USA) and Microsoft Excel 2003 (Microsoft Corporation, USA). In order to optimise the image analysis, a threshold method was used for conversion to a binary image. Five crumb grain features were determined from the field of view and were subsequently analysed to generate a crumb grain profile for each pan bread. The crumb grain features studied were: mean cell area, cells/cm^2, cell to total area ratio, wall to total area ratio and crumb area to total cells ratio [6].

Sensory analysis

Sensory analysis of fresh and stored breads was performed with a panel of eight trained judges using semi-structured scales, scored 1–10. Evaluated attributes were grouped into visual (cell uniformity, size, brightness and shape and cell wall thickness), textural (tactile moistness, elasticity and smoothness), and biting (coarseness, adhesiveness, cohesiveness, chewiness, crumbliness and dryness) and organoleptic (taste intensity, quality, saltiness, sourness and aftertaste, and aroma intensity, quality and sourness) characteristics [12, 14].

Statistical analysis

Multivariate analysis (factor analysis and correlation matrix) of data was performed using Statgraphics V.7.1 program (Bitstream, Cambridge, MN, USA).

Results and discussion

Colour measurements

Colour is considered as a fundamental physical property of foods, bread included, since it has been largely proven that it correlates well with other physical and sensory indicators of product quality [16, 17, 22]. Colour can be rapidly analysed using novel techniques such as computerised image analysis (Photoshop system) in which food images are captured using a digital colour camera or using a scanner. These systems not only offer a methodology for measurements of uneven coloration but it can also be applied for the assessment of many other attributes of whole appearance [16]. The mean values of *L*, *a*, *b* parameters measured by colorimeter and Photoshop are shown in Fig. 4. Divergences between colour coordinates evaluated by two different used methodologies were observed. With some exceptions, standard deviation bars were higher for colour coordinates measured by Photoshop system than those measured by Minolta colorimeter. When the total surface was considered for measurements to provide a representative colour picture, surface heterogeneities in samples account for greater dispersion in colour coordinates (Photoshop) when compared to precise

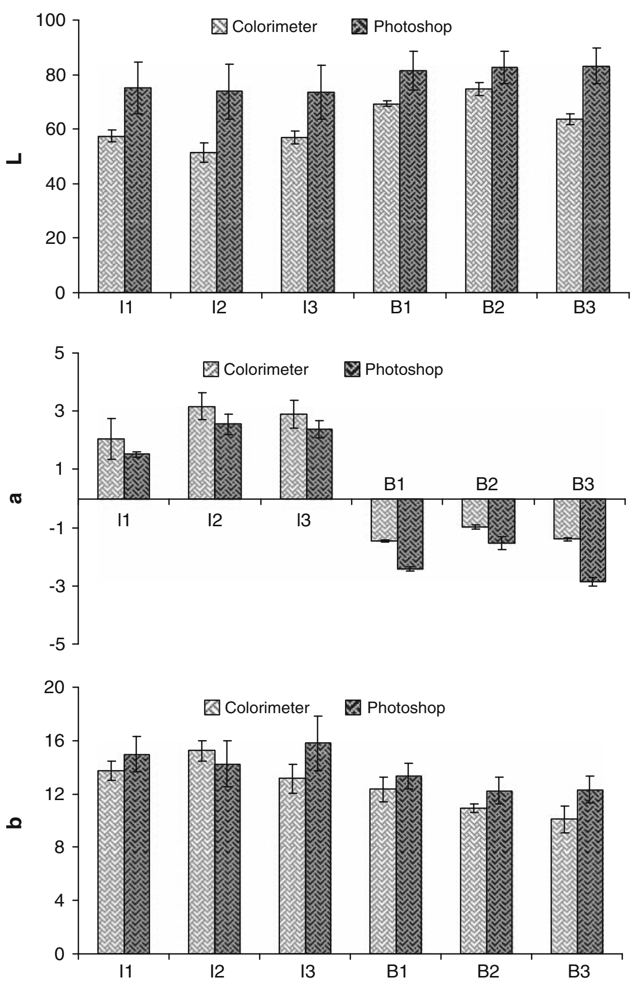

Fig. 4 Mean values ± standard deviation of colorimeter and Photoshop colour attributes of white/whole commercial pan breads. See bread formulation in Sect. "Materials and methods"

measurements over a few square centimetres (Minolta). Higher values of lightness (*L*) and yellowness (*b*) and lower values of redness/greenness were obtained when the total whole/white bread crumb surfaces were considered for colour analysis compared to data measured using a conventional colorimeter. Whole pan bread samples showed lower values of lightness than those measured for white samples regardless the analytical method used. Moreover, both techniques revealed that whole samples tend to the red colour, whilst white samples do to green colour. Red colour in whole breads can be attributed to the presence of visible brownish bran particles included into bread formula. The analysis of the entire crumb/crust surface (Photoshop system) is a valuable versatile and simple technique that permits a better achievement to set more representative information than the one obtained with branded colorimeters. This method also allows the detection of certain anomalies/defects and/or characteristic features (wheat bran, seeds, fibre particles) in bread and other heterogeneous materials. Considering all these encouraging features, entire surface evaluation provides parameters that might be strongly linked to consumer perceptions than those acquired by measuring only a small surface area of the product.

Crumb grain characteristics

It is a common agreement that good quality bread should have a high porosity and fine, regular gas cell structure in the crumb [2, 23, 24]. Grain attributes are even more important in crumb breads since grain characteristics play a key role in both white and whole pan bread acceptability [6]. Heterogeneity in cell distribution (Fig. 5) and in the values of mean cell area, cells/cm^2, cell to total area ratio, wall to total area ratio and crumb area to total cells ratio (Table 2) were found for both white and whole commercial pan breads. I2 and B2 samples showed, respectively, the highest and the lowest values for mean cell area and for cell to total area ratio as it is also observed in crumb images (Fig. 5). All the whole pan breads showed a more opened crumb structure than those observed for the white samples. This phenomenon was especially evident for I2 and I3 samples in which the highest values for mean cell area and cell to total area ratio were observed (Table 2). In general, white breads showed rounder and more uniform crumb cells with thicker and duller cell walls, whilst the whole samples look like more uneven and bigger crumb cells. The great variability of the obtained crumb grain features, for both white/whole pan breads, demonstrated that even in commercial samples there is a high product heterogeneity. This make obvious that also when a well-established production technology is used, it is quite complicated to obtain baked goods with standard characteristics.

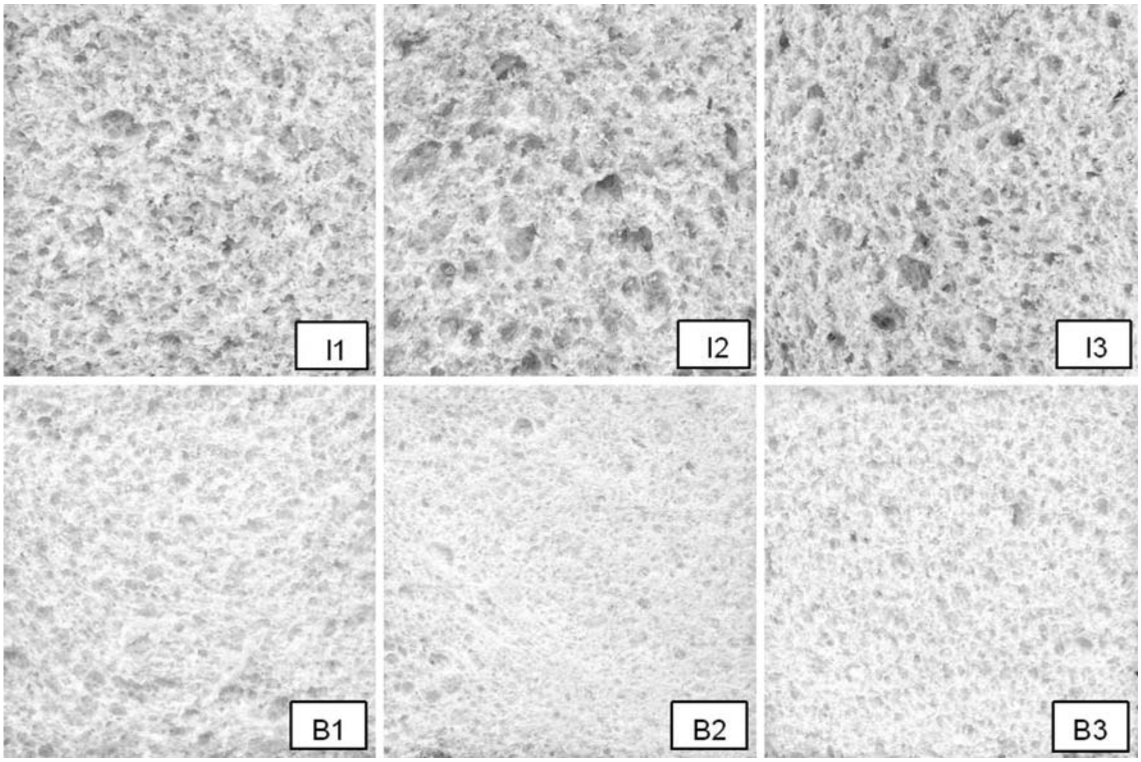

Fig. 5 Crumb structure of white/whole commercial bread crumbs (5.5 cm × 5.5 cm areas). See bread formulation in Sect. "Materials and methods"

Table 2 Crumb grain characteristics of fresh white/whole commercial pan breads (mean value ± standard deviation)

Sample code	Mean cell area (mm^2)	Cells/cm^2	Cell to total area ratio	Wall to total area ratio	Crumb area/total cells (mm^2 per cell)
I1	0.42 ± 0.01	57.34 ± 0.9	0.24 ± 0.01	0.76 ± 0.01	1.32 ± 0.02
I2	0.63 ± 0.01	48.40 ± 1.2	0.30 ± 0.01	0.70 ± 0.01	1.44 ± 0.01
I3	0.50 ± 0.02	58.38 ± 1.3	0.29 ± 0.02	0.71 ± 0.02	1.22 ± 0.05
B1	0.43 ± 0.01	56.92 ± 0.8	0.24 ± 0.02	0.76 ± 0.01	1.33 ± 0.02
B2	0.34 ± 0.01	55.68 ± 1.9	0.19 ± 0.01	0.81 ± 0.01	1.46 ± 0.05
B3	0.40 ± 0.01	49.16 ± 1.7	0.20 ± 0.01	0.80 ± 0.01	1.62 ± 0.09

See bread formulation in Sect. "Materials and methods"

Sensory analysis

The appearance and tactile perception of bread texture seems to be a decisive criterion for consumers' acceptability. How the crumb feels by touch or in the mouth is greatly influenced by the size or the structure of the crumb cells: finer, thin-walled, uniformly sized cells yield a softer and more elastic texture than coarse and thick-walled cell structures [24]. Sensory scores of the commercial white/whole fresh pan bread samples tested are depicted in Fig. 6a, b, respectively. Results from sensory evaluation indicated that for both types of samples there is a high variability of the data due to the normal heterogeneity of commercial brands. A cursory look at the figure shows that mean scores for all bread sample sensory attributes were generally high and well overall rated by judges. Finally, as considered parameters have been quoted in function of the flour extraction rate, it is not possible to define a general tendency for the analysed commercial pan bread samples.

Static and dynamic rheological measurements and sensory appreciation

Good crumb quality is dependent on several rheological and physical properties achieved by both small and large deformation measurements. The mean values of stress measured by the proposed dynamic method and the data obtained from the relaxation test for the fresh white/whole pan bread samples are reported in Table 3. Particular attention should be paid to the results obtained by the two techniques. Data acquired by oscillatory measurement (stress) showed that the whole samples were slightly

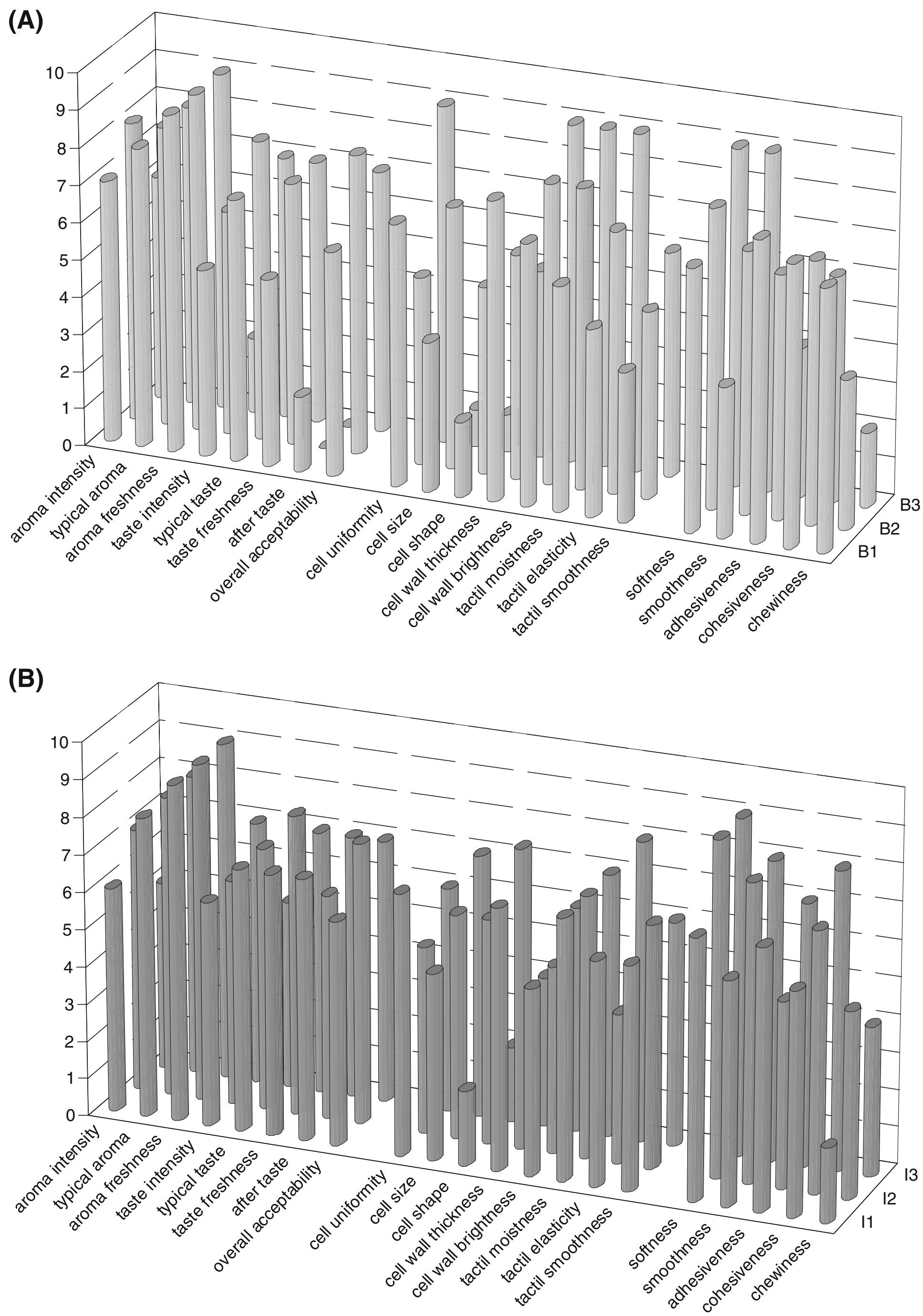

Fig. 6 Mean values of sensory characteristics in fresh white (**a**) and whole (**b**) commercial pan breads. See bread formulation in Sect. "Materials and methods"

tougher than the white ones (Fig. 7), whilst F_0 (Table 3) and all the other parameters (data not shown) obtained by mimetic tests did not appreciate differences amongst samples. In addition, a poor dependence of the stress on the frequency was observed regardless the sample type, endorsing their solid-like behaviour (Fig. 7). Both dynamic and static measurements are addressed to the evaluation of crumb firmness but fundamental tests are strictly linked to micro-structural characteristics, whilst large deformation techniques are related to crumb macro-structural features.

Pearson correlation analysis provided a range of significant correlation coefficients (r) (from 0.34 to 0.96) for the relationship between several parameters obtained from the described different analyses of fresh and stored breads ($n = 18$) (Table 4). In accordance with others studies [12, 14], static and dynamic bread crumb rheological attributes were correlated illustrating that both techniques can be useful in evaluating crumb textural characteristics. In addition, sensory perceiveness of breads with regard to the softness and the overall acceptability exhibited negative

Table 3 Rheological characteristics of fresh white/whole commercial pan breads (mean value ± standard deviation)

Samples	Dynamic test		Static test	
	Stress (Pa)	F_0 (g)	k_1	k_2
I1	8.25 ± 0.49	18.87 ± 1.03	0.347 ± 0.09	1,77 ± 0.13
I2	6.35 ± 0.35	12.02 ± 0.99	0.451 ± 0.11	1.65 ± 0.16
I3	7.15 ± 0.35	19.76 ± 1.23	0.382 ± 0.06	1.82 ± 0.09
B1	6.70 ± 0.14	25.87 ± 2.04	0.351 ± 0.10	1.82 ± 0.15
B2	5.68 ± 0.12	15.35 ± 0.97	0.265 ± 0.04	1.73 ± 0.08
B3	5.68 ± 0.15	21.38 ± 1.78	0.364 ± 0.13	2.08 ± 0.10

See bread formulation in Sect. "Materials and methods"

F_0 initial force, k_1 stress decay rate, k_2 residual stress

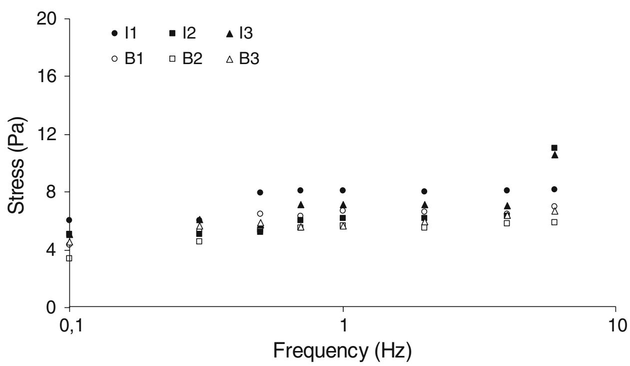

Fig. 7 Stress frequency dependence of fresh white (*I*) and whole (*B*) commercial pan breads

correlation ($-0.44 > r < -0.72$) with either dynamic stress or static F_0. It is observed that the tougher the crumb, the lower rates the consumer gave to commercial pan breads. The relationships between dynamic and static measurements evidenced negative correlations (r from -0.67 to -0.84) between static parameters (k_2, cohesiveness, springiness and resilience) considered as bread quality indicators [7] and viscoelastic dynamic measurement (stress). On the other hand, positive correlations (r from 0.60 to 0.76) were found between stress and firmness, F_0, k_1, hardness and chewiness; the obtained results are in accordance with the fact that all those parameters increased in aged breads. Despite the fact that empirical measurements are closely linked to macroscopic features, whilst dynamic tests are strongly linked to molecular characteristics, it seems from the obtained results that both techniques are complementary and derived instrumental parameters are related to some sensory attributes.

Factor analysis classified Avrami parameters (Fig. 8) into two different factors (Table 5) explaining 91.38% of the variability of the results (VE). Factor 1 (54.69% VE) grouped T_∞ (final crumb firmness) and n (Avrami exponent), whilst factor 2 (36.69% VE) grouped k (rate constant) and T_0 (crumb firmness of fresh bread). Factor 1

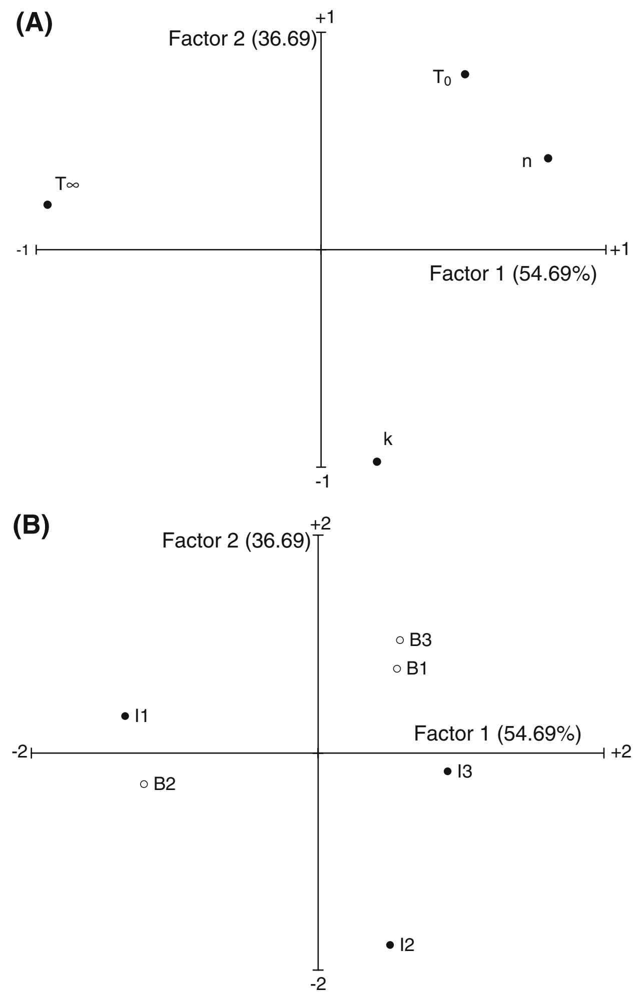

Fig. 8 Plot of Avrami parameters (**a**) and samples scores (**b**) of white/whole commercial pan bread samples after performing factor analysis. See bread formulation in Sect. "Materials and methods"

negatively correlated with aged crumb firmness and positively with the Avrami exponent, whilst factor 2 negatively correlated with firming rate, and positively with "just baked" crumb firmness (Table 5). Plots of Avrami parameters and sample scores of factor 1 versus factor 2 are depicted in Fig. 8. Separation of samples along the x-axis was observed according to T_∞ and n. I1, with high value for final crumb firmness and B2, with high values for final crumb firmness and low values for n, were located in the negative zone of the axis (Fig. 8). On the contrary, I3 characterised by intermediate values for T_∞ and high values for n was located in the positive zone of x-axis (Fig. 8). Factor 2, explained lower than 55% of the cumulative variance, was helpful for classing cases in terms of initial (fresh bread) crumb firmness values and k (rate constant). Factor 2 was able to discriminate I2, located in the negative region of y-axis, which stands out for its lower T_0 and high k and B1 and B3, located in the positive region of y-axis,

Table 4 Significant relationships amongst quality features of commercial fresh and aged pan bread samples

	Stress (Pa)	Firmness (g)	F_0 (g)	k_1	k_2	Hardness (g)	Springiness	Cohesiveness	Chewiness (g s)	Overall acceptability
Firmness (g)	0.62**									
F_0 (g)	0.74**	0.88**								
k_1	0.63**									
k_2	−0.76**		−0.34*	−0.75**						
Hardness (g)	0.76**	0.94**	0.83**	0.42*	−0.49**					
Springiness	−0.76**		−0.50**	−0.66**	0.74**	−0.44**				
Cohesiveness	−0.84**	−0.64**	−0.76**	−0.60**	0.70**	−0.73**	0.81**			
Chewiness (g s)	0.60**	0.94**	0.78**		−0.38*	0.96**		−0.62**		
Resilience	−0.67**	−0.39*	−0.59**	−0.49**	0.69**	−0.48**	0.86**	0.86**	−0.41*	
Softness	−0.50**		−0.44**							0.65*
Overall acceptability	−0.71*		−0.72*							

F_0 initial force, k_1 stress decay rate, k_2 residual stress

*$p < 0.05$, **$p < 0.01$

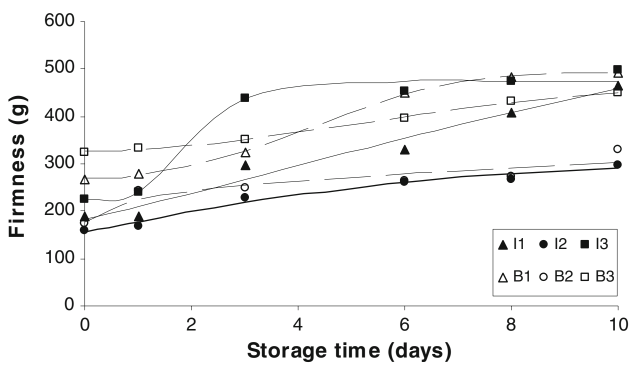

Fig. 9 Fitted values of crumb firmness during storage of white/whole commercial bread samples

that were instead separated in function of their lower values of k and medium-high values of initial crumb firmness (Fig. 8). Trends observed in this study (Fig. 9) do not permit to cluster white or whole commercial pan bread samples on the basis of their crumb firming kinetics behaviour.

Conclusions

A plural physical approach has been used in order to evaluate the physical and mechanical properties of white/whole commercial pan bread samples. Colour measurements, image analysis, sensory evaluation and dynamic and static rheological tests provided significant differences amongst commercial samples. Higher values of lightness (L) and yellowness (b), and lower values of redness/greenness were obtained when the entire whole/white bread crumb surfaces (Photoshop) were considered for

Table 5 Sorted rotated factors loadings of Avrami parameters during aging of commercial pan breads

Parameters	Factor 1 (54.69% VE)	Factor 2 (36.69% VE)
T_∞	−0.96	
k		−0.98
n	0.80	
T_0		0.80

T_0 crumb firmness of fresh bread, T_∞ final crumb firmness, k rate constant, n Avrami exponent

colour analysis compared to data measured using a conventional colorimeter (Minolta). White breads showed rounder and more uniform crumb cells with thicker and duller cell walls, whilst whole samples exhibited more irregular porosity and bigger crumb cells. Data acquired for fresh bread samples by the proposed new oscillatory technique performed in a conventional texturometer showed that the whole samples were slightly harder than the white ones. Significant relationship (r from 0.34 to 0.96) amongst several rheological and sensory features obtained from the described different analyses during bread storage was found.

As data achieved using the proposed novel approaches might be better linked to the consumer awareness than those obtained from classical analyses, the obtained results are quite promising for a proper bread crumb quality assessment.

Acknowledgments Authors acknowledge the financial support of the Spanish Institutions Consejo Superior de Investigaciones Científicas (CSIC), Ministerio de Educación y Ciencia (MEC-Post Doctoral Contract NRP 0000317068NU0SC000057) and Ministerio de Ciencia e Innovación (Project AGL2008-00092/ALI).

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