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A new approach of sensorial evaluation of cooked cereal foods: fractal analysis of rheological data*

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Abstract. An analytical method based on a fractal geometry concept was developed through the relationship between structure-texture of solid-like crackers, flat bread and Bretzels. An universal testing machine was used to determine indentation tests. The graphs were irregularly shaped so that usual interpretation was made not possible. Nevertheless, the irregular shape, or "roughness" displays auto-similarity properties which can be interpreted in terms of apparent fractal dimension texture (D_T). A trained panel able to quantify the "hardness", "porous structure" and "crispness" descriptors carried out sensorial characterisation of products. High correlation between sensorial hardness and resistance to indentation, on one hand, and between crispness and D_T on the other hand was found. Modelling mathematics methods for complex systems allow useful contribution to Food Science.

PACS. 61.43.Hv Fractals; macroscopic aggregates (including diffusion-limited aggregates) – 83.10.Tv Structural and phase changes – 62.20.Mk Fatigue, brittleness, fracture, and cracks

1 Introduction

Cereal-based cellular food industry (biscuits, crackers, cookies...) is an important sector of the food industry. It is well established in all industrialised countries and rapidly expanding in the developing areas of the world. Manufacturing processes (cooking extrusion, extruding, depositing and laminating) linked to the composition of the product (fiber content [1], bran [2], food additives [3], fats and oils [4], sugar and syrups [4], moisture contend and water activity [5]. provide a wide range of very different products. This diversity renders the quantitative determination of the structural quality of products, in terms of "hardness" and "crispness" descriptors for example, extremely difficult.

Indeed products usually present:

- A porous structure (about 60 to 90% [6] of the total volume) where the number, the size and the size distribution of pores result from the ability of starch to gel.
- A highly anisotropic structure [2,6,7], internally heterogeneous [8,9].

Instrumental methods such as bending, compression, shear tests or pin indentation method usually study the structure of food foam products.

For these materials, the exploitation of the mechanical tests is difficult. The graphs (force *versus* deformation) were irregularly shaped so that usual interpretation was made not possible. Nevertheless, the irregular shape, or "roughness" displays auto-similarity properties, which can be interpreted in terms of apparent fractal dimension. It seems to be interesting to tackle the problem by non-classical methods and consider the food materials responses from a mathematical and physical point of view.

In the present work, the quantification of irregularities was then made by an image analysis system allowing determination of apparent fractal dimension. A trained sensory panel for their characteristics evaluated the products. A correlation was attempted between sensory properties and apparent fractal dimensions.

2 2 Materials and methods

2.1 Materials

Fourteen commercially available products (Tab. 1) were purchased in a local supermarket. Products were selected according to their heterogeneous structure. The moisture content is lower than 6%.

2.2 Mechanical measurements

The Instron Universal machine model 1122 (Instron Corp., Canton, MA) equipped with a 1000 N load cell was used

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Table 1. Commercially available products used for the study.

Products	Brands	Products	Brands
Biscotte®	Heudebert	Cracotte®	Heudebert
Bretzels®	Bahlsen	Bretzels®	Production by craftsmen
Edition spéciale®	Belin	Extra brun®	LU
Galette de blé®	Gerblé	Grillé Pelletier®	Heudebert
Petit Beurre®	LU	P'tit Nature®	Bjorg
Sablé des Flandres®	Belin	Thé®	LU
Toast Brioché®	Heudebert	Triangulini®	Belin

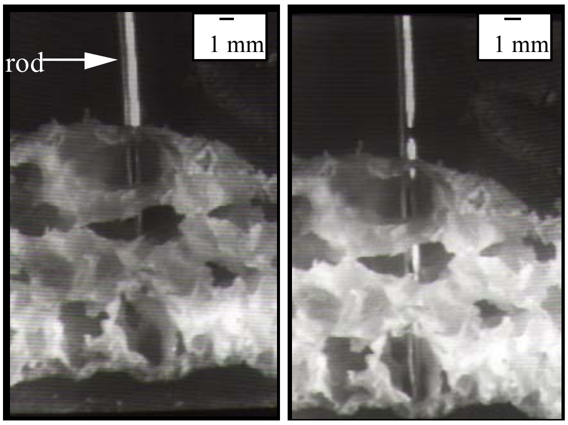

Fig. 1. Mechanical measurements of the texture by indentation.

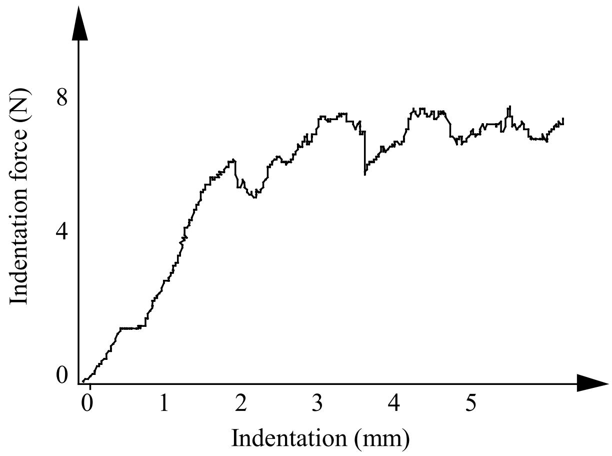

Fig. 2. Indentation profile obtained (Triangulini®, Belin).

with a rod of 1 mm diameter held in a chuck mounted on the crosshead. The rod was uniaxially driven into the foam (Fig. 1) at a crosshead speed of 0.5 mm min^{-1}. The indentation is realised on the centre of the sample.

All the tests were performed in triplicate.

2.3 Determination of the apparent fractal dimensions

The apparent fractal dimensions (D_T) were determined as follows [10,11]: the signal (recordings indentation, Fig. 2) was normalised by a four-polynome degree (Fig. 3, $n = 1$). The normalised curve was dilated 50 times by the principle of Minkowski [12] using an image analysis software (Visilog 3.6 by Noesis). The algorithm of Minkowski (iteration of the dilations) was applied to a curve and led to the "saucisse" of Minkowski increasing at each iteration and developed by many authors working with fractal dimensions [13,14]. For each dilation n, we calculated the length L of the curve (Fig. 3, $n > 1$).

$$L = Area/2n.$$

The slope of the linear region of the Richardson plot ($\log L$ *versus* $\log n$) gave the apparent fractal dimension of the curve [15].

$$D_T = 1 + |P|.$$

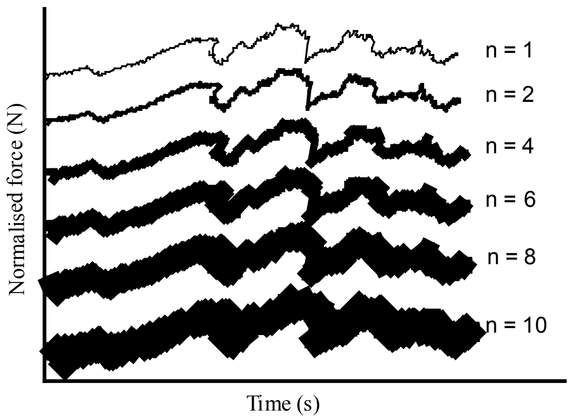

Fig. 3. Example of normalised and dilated curves by the principle of Minkowski.

This fractal dimension was considered as an apparent fractal dimension because it was limited in a range of length scale and only described macroscopic details.

The validity of the results of fractal dimension determination was tested with the Weierstrass function, generated by a computer, whose fractal dimension was known. It was demonstrated that as long as the resolution along the two axes was the same, the calculated fractal dimension provided an absolute, rather than a relative, measure of the relationships jaggedness [15,16].

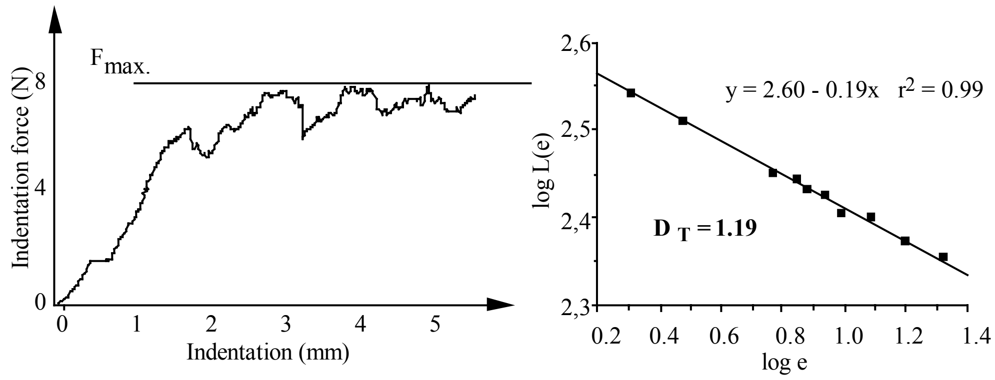

Fig. 4. Example of indentation curve obtained (Triangulini®, Belin) and determination of the apparent fractal dimension.

The Weierstrass function was defined as:

$$f_w(x) = \sum_{i=1}^{\infty} \left[\sin\left(\lambda^i x\right) / \lambda^{\varepsilon i}\right]$$

where λ ($\lambda > 1$) and ε ($0 < \varepsilon < 1$) are constant.

2.4 Sensory analysis

2.4.1 Panel and sensory methodology

A panel of 19 members was selected, based on their ability to describe texture an classify products. Criteria for selection were as described by Civille and Szczesniak [17]. The panel was composed of 14 women and 5 men ranging in age from 20 to 30 years. It consisted of students, food scientists and technologists. The judges were trained to evaluate texture during ten hourly sessions. The training consisted of discussions and demonstrations of basic techniques for textural evaluation. The sessions of sensory analysis were realised from 12 h to 13 h in a normalised room [18]. All the sensory parameters were evaluated descriptively and transformed into a 1–5 numerical scale for data analysis. Each value corresponded to the mean of sensory intensities given by the 19 members. Six samples were evaluated at each session. Three identical sessions were held to test the reproducibility of panel results. Standard deviation was below 10% for each member.

2.4.2 Vocabulary development

A sensory vocabulary for description of bead-crumbs was developed [19]. Three final terms were selected for this study: "hardness" (sensory perception tactile) and "crispness" (sensory perception in mouth), "porous structure" (sensory perception visual).

3 Results and discussion

One example of indentation curve obtained and determination of apparent fractal dimension are shown in Figure 4.

Table 2. Repeatability of the methods on the product "Petit Beurre®" of LU (fractal, rheology and sensory analysis, mean of 19 measurements).

	Mean	Standard deviation (%)
D_T	1.23	1.6
$F_{\max}$	15.6	6
Sensory analysis:		
Porous structure	0.7	10
Crispness	1.2	6
Hardness	2.7	4

The standard deviation of sensory attributes (hardness, crispness and porous structure), rheological characterisation and determination of apparent fractal dimension (Tab. 2) are weak and allow for the repeatability of the methods.

Nevertheless, it was observed that the standard deviations were sharply weaker in the case of calculation of the apparent fractal dimension (1.6%) than for sensory analysis descriptors, and more particularly in the case of visual determination of the porous structure of the products (10%).

Quantitative evaluation and comparison of the ruggedness degree of different indentation curves were difficult to achieve with classical methods. Quantification was made possible by determination of the apparent fractal dimension D_T using Minkowski's principle. Table 3 gives the different values of apparent fractal dimension, the intensities of the sensory attributes and the rheological characterisation for each product. The apparent fractal dimension D_T modelled the fluctuations of curves representative of the indentation behaviour of the products. As already explained, the apparent fractal dimension D_T was a measurement of the overall jaggedness or ruggedness of the curves.

The degree of irregularity of the experimental curves was itself a manifestation of the deformation mechanism and this property, revealed by the apparent fractal dimension of the indentation curves of the products, should be treated as a textural characteristic [10].

Table 3. Values of apparent fractal dimension, the intensities of the sensory attributes and the rheological characterisation for each product (mean of triplicate measurements).

	Instrumental analysis		Sensory analysis		
Products	D_T	$F_{\max}(N)$	Porous	Hardness	Crispness
Biscotte®	1.16	8	4.5	1.4	4.2
Cracotte®	1.09	8.5	4.7	2.2	4.9
Edition Spéciale®	1.20	13.5	2.6	1.8	2.6
Extra Brun®	1.21	12	2.4	1.9	1.8
Galette de blé®	1.23	29	1.3	3.4	3.4
Grillé Pelletier®	1.14	6	4.8	1.7	4.2
Petit Beurre®	1.23	33	1.7	3.1	2.2
P'tit Nature®	1.23	12.5	1.2	2.4	1.3
Sablé des Flandres®	1.20	14	1.4	1.8	1.8
Thé®	1.19	8	3.5	1.9	2.3
Toast Brioché®	1.10	7.5	4.3	1.9	3.9
Triangulini®	1.19	8.5	2.5	1.0	3.3
Bretzels® craftsmen	1.28	24	0.8	2.8	0.5
Bretzels® Bahlsen	1.35	22	0.2	3.2	0.8

The textural properties were, in our case, the hardness, the crispness and the porous structure of the product, which were a macroscopically feature dependent on the structural organisation of the different components.

Recordings as well as analysis of Table 3 allowed discrimination of three different behaviours during the indentation experiments.

- A first one was relatively "smooth" with dramatic breaks of the force applied (probably a collapse of the whole structure). Such a recording was obtained for products belonging to the family of flat breads (Biscotte®, Cracotte®, Grillé Pelletier®, Toast brioché®). This family displayed the weakest apparent fractal dimension dimensions ($D_T = 1.12$ on average).
- A second one was representative of the products known as solid- like crackers (Edition spéciale®, Extra brun®, Galette de blé®, Petit beurre®, P'tit nature®, Sablé des Flandres®, Thé® and Triangulini®). The recordings exhibited a much "roughness" aspect and were characterised by a bigger apparent fractal dimension ($D_T = 1.22$ on average).
- A third typical behaviour of the so-called Bretzel family (Bahlsen and production by craftsmen) was the recordings of very "roughy" aspects and was characterised by the biggest apparent fractal dimension ($D_T = 1.31$ on average).

Figure 5 also put into evidence the three families of products. Good correlations were found, on one hand between sensory hardness and indentation resistance force ($r^2 = 0.77$), and on the other hand between the apparent fractal dimension and "porous structure" as well as "crispness" descriptors (r^2 being respectively 0.80 and 0.83).

Results showed that the "crispness" descriptor of the products in mouth was more pronounced when the size of pores increased. Such the products were characterised by the weakest apparent fractal dimension. Therefore it can be concluded that apparent fractal dimension is more representative of the microstructure of the products than of their macrostructure.

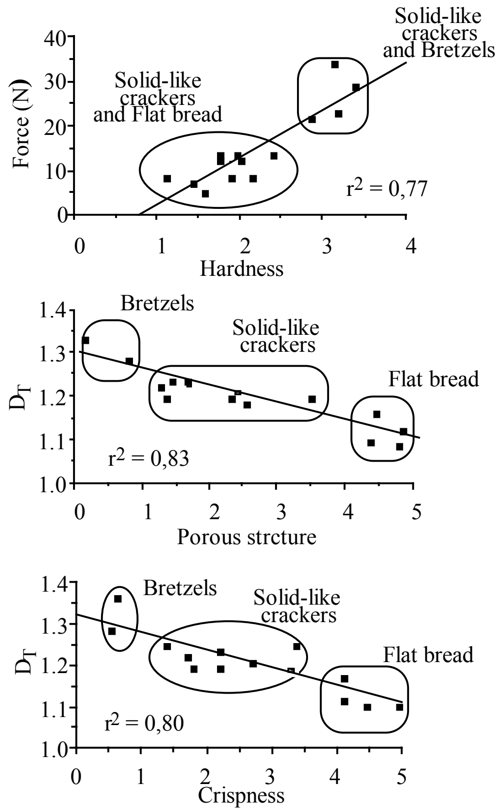

Fig. 5. Instrumental analysis as a function of sensory analysis.

4 Conclusion

The apparent fractal dimension of the normalised curves was a modelisation of the irregular mechanical signatures of the cooked cereal foods. The relationship between sensory analysis and apparent fractal dimension was an interesting tool for quantitative prediction of crispness aspect.

Substitution to sensory analysis can be imagined through on-line measurements of the textural quality.

Modelling mathematics methods for complex systems should allow useful contribution to Food Science.

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