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Assessment of French bread texture by a multi-indentation test

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ABSTRACT

A specific equipment, made of an assembly of 10–20 vertical metal pins, has been implemented to assess the crusty texture of French breads by a so called multi-indentation test. It was connected to a force sensor set on a material testing machine in the range [0; 100 N]. The height of each pin was adjustable to the irregular surface of the crust of the tested specimen. Breads with varying texture were prepared under various dough mixing conditions and formats, different baking times (8, 11, 15 and 17 min), and with various contents of bioprocessed fibres. They were crushed, by the multi-indenter at a constant rate (50 mm/min), followed by a relaxation step while maintaining stable the final strain at 2/3rd of the initial sample height. Main variables measured from the resulting texture profile were related to crust stiffness and crumb firmness. The relevant bread format, accurate baking time and fibres content could be selected in function of given crust properties. Overall, the multi-indentation test proved a useful procedure to contribute to the design of breads with target texture.

1. Introduction

The crust of French bread (or "baguette", depending on its format) is one of its main feature since it gives its crispiness. This textural property is based on a combination of composition (low moisture), intrinsic morphology (biopolymer blends) and geometry (thickness) that depends on bread processing conditions (Roudaut et al., 2002; Luyten et al., 2004; Purlis and Salvadori, 2009; Primo-Martin et al., 2010). Due to its heterogeneous appearance, the texture of French bread has been difficult to assess; in comparison, for example, the mechanical properties of pan bread could be evaluated by a simple compression/relaxation test performed on its crumb, or even a "profile texture analysis" (TPA) (Scanlon and Zghal, 2001). Indeed, besides the difficulty owing to the ambiguous definition of crust, well underlined by Vanin et al. (2009), the crust of French bread presented an irregular surface with scale pieces of various sizes. This traditional feature has certainly been part of its attractiveness for the consumer, but it has made its mechanical testing a challenge.

Various procedures could be thought of for testing French bread texture. Simple compression of bread between two plates could hardly be envisaged, since crust surface is too irregular. Conversely, puncturing crust surface with a simple rod, or with a needle, would require a huge number of repetitions. Recently, Altamirano-Fortoul et al. (2013) have studied the texture of bread crust by puncturing tests; in this case, it seems that breads surface was regular enough for the number of measurement repetitions to be realistic.

Conversely, other works have been performed by removing the crust from bread in order to perform direct measurements on such samples. These studies have led to interesting results because they have allowed a deeper analysis of crust, and its properties: permeability (Hirte et al., 2010), porosity (Altamirano-Fortoul et al., 2012). Primo-Martin et al. (2009) proposed another approach by preparing model crusts, i.e. carefully processed material samples on which physical properties could be determined. However, in that case, the influence of bread processing could hardly be tested, although valuable works were performed to assess the formation of bread crust (Vanin et al., 2010) by thermo-mechanical analysis. In all cases, the uncertainties, due to the definition of the crust and to the handling of the sample, challenged the application of these methods to French bread.

Finally, modelling has sometimes been inferred when experimental issues are too difficult and it could be used in order to define the relevant structure, and hence the processing conditions, that would lead to the expected texture. For instance, Liu and Scanlon (2003) have modelled bread crumb indentation by finite element analysis. Similar approach has also been suggested to determine the viscoelastic properties of vitreous starch/protein blends (Guessasma et al., 2008), i.e. a biopolymers composite similar to bread crust (Primo-Martin et al., 2006). In every case, the intrinsic properties of the materials and its phases

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Nomenclature

A_i	cross section area of an indent (7.07 x 10^{-6} m^2)
E_{bread}	apparent modulus of bread crust (Pa), derived from initial force (displacement) curve
[Enz]	concentration of enzyme added in the composition of the bread based on flour weight (mg/g)
E_s	specific mechanical energy delivered to the dough during mixing (J/kg)
F_m, $F_{2/3}$, F_r	force at the debonding of crust during compression, at the end of compression and at the end of relaxation (N), respectively
[Fibres]	amount of fibers added in the composition of the bread based on flour weight (%)
PCA	principal component analysis
T_d	dough temperature at the end of mixing (°C)
W	crushing energy computed by the area below force (N)–displacement (m) curve till the end of compression step (J)
$\rho*$	bread density (g/cm^3)
σ_m, $\sigma_{2/3}$, σ_r	apparent stress at the debonding of crust during compression, at the end of compression and at the end of relaxation (Pa), respectively

have still been unknown (Guessasma et al., 2011) and there has been a need to find a compromise between a robust method which would deliver an overall signal relative to the texture of bread and a more precise one which would give local information.

In this context, the aim of this paper was to propose a simple test for French bread texture that could reflect crust and crumb properties. In order to obtain different textures and crust/crumb features, we have processed and tested breads with different formats, used various dough mixing conditions, at different baking times, and having different fibre contents.

2. Materials and methods

2.1. The multi-indentation apparatus and test

The principle of multi-indentation was based on measuring resistance of crust and crumb against compression applied through an universal testing machine (type #1122, Instron Corporation, Canton, MA, US). The device consisted in a fixed plate and a crosshead on which different attachments could be mounted, depending on the bread to be tested. It was provided with a force sensor applied in the range [0, 100 N]. Force signal was acquired at a frequency of 20 Hz through a PCI-DAQ 16 bits card interfaced with the software LabVIEW (National Instruments Corporation, Austin, TX, US).

Samples were submitted to a compression by a specific device consisting of several indents, which are cylindrical iron made pins, Ø 3 mm, with a conical tip of 40°. The number of indents depended on the type of bread, varying from 2 × 5 for mini-breads and traditional French breads, to 2 × 10 indents for baguettes. Samples of 12 cm length were cut in case of traditional French breads and baguettes. The bread, or piece of bread, was placed horizontally so that the indents came in contact with the middle part of the upper bread surface (Fig. 1a–c). For geometrical constraints, the plate supporting the indents was oriented axially, thus indents were aligned in the direction of the length of bread for the small bread and baguette, whereas they were oriented in the transverse direction, i.e. orthogonal to main axis for bread. The maximum average height of the bread ($h0$) was measured with a vernier calliper, by taking six different values from three different baked samples of the same dough batch. The indents were individually adjusted to come in contact with the crust surface of the bread, by making the pins slide and rest just at the surface, at different lengths according to the profile of the crust; then they are fixed in the plate thanks to a screw and secured so that each one indents the crust effectively at the same time. The crosshead was moved down at a speed of 50 mm/min and stopped after a distance equal to 2/3rd of maximum average height ($h0$). The crosshead speed was only slightly higher than the value (0.5 mm/s) recommended by Altamirano-Fortoul et al. (2013) to relate measurements to crispness properties. After compression, the bread was allowed to relax for 120 s, i.e. 3 times the time of compression.

The different variables defining mechanical behavior were shown in Fig. 1d. Initial slope Sl, was obtained by computing the initial slope of the force–displacement curve. The force measured at the slope change was defined as the maximum force (Fm). The force measured when crosshead displacement equaled to 2/3rd of the average initial height of the bread ($h0$), was noted $F_{2/3}$. According to breads type (standard, mini-bread, or baguette) we could find either $F_m \leqslant F_{2/3}$ or $F_m \geqslant F_{2/3}$. The crushing energy, W (J), was computed by the area under the force–displacement curves, F (d), during the compression phase. Finally, the residual force (F_r) was obtained at the end of the relaxation step. Forces signal were then normalized by computing their ratio to the total section area of the indents n_i . A_i, in order to be able to compare the results obtained under different configurations of the multi-indenter (number of pins, n_i, and orientation of the plate). The resulting variables computed from Fm, $F_{2/3}$, F_r and Sl, were the apparent stresses σ_m, $\sigma_{2/3}$, σ_r and apparent modulus E_{bread}, respectively. Unlike the usual plate compression test, these variables did not define

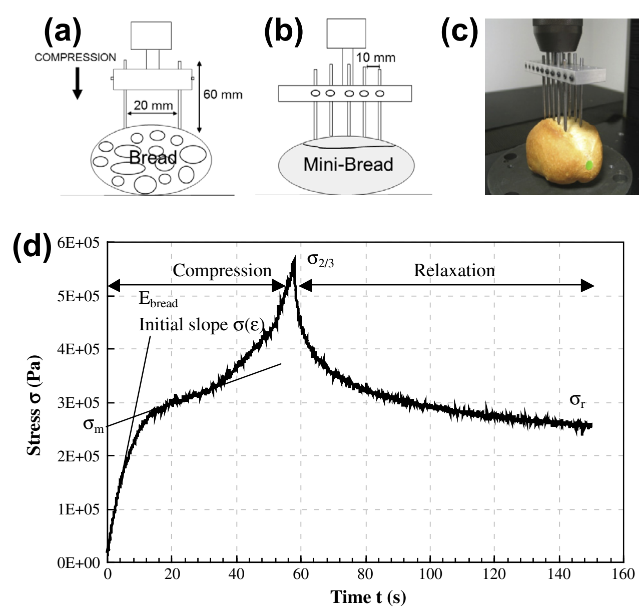

Fig. 1. Sketch of multi-indentation principle: application of the multi-indenter on (a) transversal bread and (b) axial baguette section, and (c) photo on mini-bread and (d) typical curve of apparent stress, obtained during multi-indentation test and main mechanical properties determined.