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# Impact of the baking kinetics on staling rate and mechanical properties of bread crumb and degassed bread crumb

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This paper presents a study on the impact of baking conditions on crumb staling. Breads were baked at 220 °C, 200 °C and 180 °C corresponding to 6, 8 and 10 min to rise the temperature to 98 °C in the crumb (heating rates 13, 9.8 and 7.8 °C/min respectively with an initial temperature of 20 °C). A new protocol has been developed, consisting in baking a slab of degassed dough in a miniaturized oven to mimic the baking conditions of conventional bread making. Texture tests were done during staling on degassed crumb and on conventional crumb. Calorimetry tests showed that during storage, amylopectin recrystallisation occurred before crumb stiffening. A first order kinetics model was used to fit the evolution of the crumb texture (Young's modulus) and of the recrystallisation of amylopectin. The results showed that the hardening of the crumb during staling occurred after retrogradation of amylopectin. In addition, the staling rate was faster for faster baking kinetics. A mechanical model showed that the relative Young modulus is proportional to the square of the relative density of the crumb.



## 1. Introduction

Texture is maybe the most studied physical parameter of bread. Texture of the crumb, is linked to the mechanical properties of the material constituting the foam and to its structure (Liu and Scanlon, 2003). The cellular structure of the crumb can be characterized by different parameters as presented by Scanlon and Zghal (2001). These authors proposed that two macroscopic phases (crumb cells and cell walls solids) should be considered. Digital image analysis studies of bread-crumb structure allow the determination of the characteristics of these macroscopic phases. 2D images are used in most studies, whereas 3D images (ie. using X-ray tomography) can bring more accurate information. The average size of the cell can first be considered. The distributions of the size of the cells, and in turn the wall thickness are important parameters that affect the texture of cellular foam like bread crumb. The size of the cells and the thickness of the walls depend on several factors linked to the processing conditions and to the formulation. The duration of fermentation for example can have an impact on the cell distribution. During fermentation, bubble to bubble interaction starts to occur for dough porosity larger than around 50%. Therefore, a longer fermentation may result in a less uniform cell distribution. Baking at a lower temperature than for conventional baking, such as in the case of partial baking of bread usually results in a lower oven rise. The structure of the crumb of part baked bread is most of the time made of smaller cells (vs. conventional baking) with a narrow size distribution. The location of the breads in the oven can also induce an artifact. Indeed, the loaves that are installed close to the wall of the oven are exposed to different radiative heat transfer conditions than at the centre of the oven and may heat up at a different rate than the bread placed at the centre of the oven depending on the design of the oven. The bread close to the wall of the oven may also have a thicker crust. Baik and Chinachoti (2000) showed that the staling rate of bread with crust was faster than the staling of bread without crust. This was attributed to the equilibration of moisture between the crust and the crumb. During storage, the crust tends to trap moisture from the crumb, resulting in a dehydration of the crumb and in a faster staling in the case of bread with crust. Another point is that the duration of baking and the time-temperature history cannot be considered as strictly homogenous in all locations of the crumb in a given bread. The crumb located just below the crust undergoes a much longer baking than the crumb located at the very centre of the bread as shown by Marston and Wannan (1976). This difference in the

*Abbreviations:* E, Young modulus of the degassed crumb MPa); E*, Young modulus of the bread crumb (cellular) (MPa); $E_0$, Young modulus of the degassed crumb at initial time (MPa); $E_\infty$, Young modulus of the degassed crumb at end of staling (MPa); $\Delta H_0$, melting enthalpy of amylopectin at initial time (J/$g_{dm}$); $\Delta H_\infty$, melting enthalpy of amylopectin at end of staling (J/$g_{dm}$); *t*, : time (days); $\tau$ or $\tau$', time constant of first order model (days); $\rho$ or $\rho^*$, density of the degassed crumb and of cellular crumb (kg/m$^3$); $\varepsilon = \Delta L/L$, strain of the sample during compression (dimensionless).

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degree of baking between the centre and the surface of the bread increases with the size of the bread Patel et al. (2005). One impact of this is that the degree of starch gelatinization and the degree of starch granule swelling and destructuration can be non-uniform in a same bread as shown by Marston and Wannan (1976). Indeed, the duration of baking has an influence on the degree of destructuration of starch granules as shown by Borczak et al. (2008) and therefore a longer duration is supposed to have an impact on the staling rate as proposed by Boumali et al. (2008).

The review presented above shows that the processing conditions, the crust crumb ratio, the location considered in a bread … interact with the structure and therefore with the texture of the crumb. If one wants to evaluate objectively the impact of formulation or of processing on the texture of the crumb, the size of the crumb sample, the spot considered in a given slice of bread to make the texture test can induce an artifact in the data that will be obtained. Moreover, a given batch of breads cannot be considered as strictly uniform, even though a strict procedure and protocol are used. The storage temperature also plays an important role in the kinetics of staling. Storing the bread at chilling temperature (i.e. 4 °C) accelerates the staling in comparison to storage at room temperature Guinet and Godon (1994).

Standardized methods are available to measure the texture of the crumb. For example, the American Association of Cereal Chemistry (AACC, 1995) proposes a standard method based on the compression of a slice of crumb of around 25 mm thickness. The "texture" of the bread crumb is often determined as the force in Newtons measured at a selected compression ratio (i.e. 25%). The percentage of deformation is always subject to discussion as the onset of compression is determined from the increase of the force when the plunger is contacting the crumb. There is thus a certain inaccuracy in the determination of the percentage of deformation. For example, if the slice of crumb is not perfectly flat, then the force may rise before the compression is effectively applied to the slice of crumb; this may induce an error in the origin of the deformation and therefore in the force that will be determined after a given ratio of compression. Therefore, at least 3–6 repetitions must be done to obtain for the mean value one representative data of the texture of crumb. Another problem concerns the fact that small breads are often used for laboratory tests. In this case, the number of slices that can be obtained in a given bread is not very large. Sometimes, large cells can be present in the crumb (i.e. in the case of a baguette) with a size similar to the thickness of the slice. In this case, the compression test can result in wrong measurements.

The objective of this work was to develop a new protocol to assess the staling of bread crumb that allows both a good control of the processing (baking) conditions and a good control of the conditions of the texture test. In other words, the objective of this new protocol was to overcome the difficulties presented in the introduction of the manuscript. The protocol is based on the baking of a miniaturized sample of degassed dough with very well defined conditions. First results on the kinetics of staling are presented and are compared to the texture of real crumb from bread baked in similar conditions.

## 2. Materials and methods

### 2.1. Raw materials

The white flour (Moulins Soufflet Pantin – Pornic, France) used for the formulation had the following properties: 0.53 Ash content, 10.58% protein on dry matter, falling number 402 s, Zeleny 38, alveograph parameters $W = 183$, $Pm/L = 0.62$. The recipe was as follows: 100 g of flour, 58 g of water, 5 g of compressed yeast (Michard SAS – Theix, France), 2 g of salt (Esco, Levallois-Perret, France) and 1 g of improver (PURATOS – Groot-Bijgaarden – Belgium).

### 2.2. Bread-making procedure

Ingredients were mixed in an SP10 spiral mixer (VMI, Montaigu, France) during 2 min at 100 rpm and 7 min at 200 rpm. At the end of the mixing, dough temperature was between 18 and 20 °C. Dough was then rested for 15 min. It was then divided and moulded in a divider – moulder (Bongard, Holtzheim, France) to obtain 30 dough pieces of 70 g each (initial batch of dough was 2100 g). Dough pieces were pierced with 5 holes (needle piercing) and were placed in a fermentation cabinet (Panimatic, Souppes s/Loing, France) for 60 min at 35 °C, 95% relative humidity. The expansion ratio of the dough at the end of fermentation was 4.8. This relatively high expansion ratio is justified by the fact that no cuts were done on the surface of the breads before baking.

Baking was done with two different protocols. In the case of "normal" bread making, baking was done in a static sole oven (MIWE Condo, Arnstein, Germany) during 20 min at selected temperatures with 0.5 L of steam at start of baking (0.4 $m^3$ oven volume). Bread core temperature was measured with a K type thermocouple (0.3 mm diameter).

Alternatively, the dough was baked as degassed dough. In this case, at the end of fermentation, the dough was gently squeezed manually. Then 20 g of dough was placed in a plastic pouch and was vacuum treated for 1 min to remove all porosity. The pouch was then sealed and was installed in a miniature baking system made of two Peltier elements (5 cm × 5 cm) Jiang et al. (2008). The dough sample was flattened between the two Peltier elements. A spacer (3 mm) located between the two Peltier elements was used to control the thickness and the parallelism of the dough sample. A time-temperature evolution was then programmed in a control unit and the "baking" was done, including temperature rise at a pre selected heating rate, a possible plateau at crumb baking temperature (98 °C) and then a cooling step (40 min to reach 20 °C). This procedure offered a perfect control of the time temperature history of the dough during baking.

### 2.3. Kinetics of baking

Breads were baked in the oven (MIWE-Germany) with "voute" (upper heating) and "sole" (deck heating) temperatures of 180 °C, 200 °C and 220 °C. Temperatures in the bread were logged with K type thermocouples (0.3 mm diameter) connected to a data logger (SA 32 – AOIP – France). The baking duration (corresponding to partial baking) was considered at the time needed to reach the temperature of 98 °C at the centre of the bread (starting from 20 °C). Breads were then cooled down in ambient air at around 20 °C (40 min). The analysis of time – temperature histories showed that it took 6, 8 and 10 min until a central temperature of 98 °C is reached for oven temperatures of 220 °C, 200 °C and 180 °C respectively, corresponding to heating rates of 13, 9.8 and 7.8 °C/min respectively (initial temperature 20 °C and baking temperature of 98 °C). These three conditions were then considered for the baking of the degassed dough samples, considering that reaching this temperature corresponded to the case of partial baking of bread. A linear evolution of the temperature during heating was programmed on the temperature controller of the miniaturized baking system and samples were heated at the given heating rate until a temperature of 98 °C was reached. Then the samples were cooled down to 20 °C.

### 2.4. Analysis of the texture of bread and degassed crumb

Measurements were performed after 1 h equilibration at room temperature. The texture of bread was determined at day 0 at 20 °C by a compression test with a JJ LLOYD LR5K texturometer. For each measurement, 15 slices of 15 mm were used for compression tests.