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A reverse engineering approach of French breadmaking for nutritional purposes.

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Résumé

The main purpose of this work is to design breads with improved nutritional properties without modifying their acceptability. The *in vitro* glycemic index (IG) of breads, with various contents of wheat dietary fibres (DF) and different densities, was determined by α -amylolysis and correlated to *in vivo* clinical measurements. Their texture has been assessed by multi-indentation and image analysis, in order to be able to compare their mechanical properties and cell structure features to sensory criteria. All results underlined the significance of bread density, whatever the composition and processing of breads. After a survey of professional practices to collect the know-how of breadmaking and determine the most important unit operations, the study at lab scale of structural modifications during processing has focused on two main operations: dough proofing and making-up. A decrease of dough stability due to DF addition was evidenced by the follow-up of bread dough proofing by image analysis. This result was attributed to the increase of dough viscosity when adding fibres, as measured by creep-recovery tests on controlled stress rheometer. These results allowed to suggest the necessary modifications to the process by increasing water addition and decreasing proofing time when incorporating fibres.

Mots-clés : bread, dietary fibres, professional practices, rheology, texture.

1. Introduction

The French National Plan for Health & Nutrition (PNNS) recommends the increase of foods containing starch and dietary fibres (DF), spurring the addition of wheat fibres in order to decrease the glycemic index (IG) of French bread. Dietary fibres are the remnants of the edible part of plants, which are not digested and absorbed in the upper human intestine. They are mainly composed of plant cell walls, for instance in the different tissues of the wheat grain, and their variable structural features affect their properties and technological role (Saulnier *et al.*, 2007). Because of this variety and in spite of the large amount of literature describing the effect of fibres in breadmaking, there is no evidence of its effect on IG, whereas the influence of the process might be significant (Rizkalla *et al.*, 2006). From a sensorial point of view, the addition of fibres in current French bread results in a loss of crispiness of the crust, an increase of density, a granular mouth feeling and a dark crumb. All these drawbacks may limit consumer's acceptability (Martin *et al.*, 2008). Hence, two main issues challenge the adaptation of the breadmaking chain to the addition of fibres: first, improving our knowledge on the modification of wheat

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flour dough and bread properties and secondly, achieving the necessary changes to craftsmen's practices at different processing steps, since this activity is not mainly achieved at industrial scale. In this purpose, this work, developed in the frame of various ANR projects, combines experimental approach and knowledge representation in order to integrate the process-structure-property relationships of breadmaking from the molecular to macroscopic scales.

2. Material and methods

2.1 Collecting knowledge on breadmaking practices

Professional practices of craftsmen were collected by a survey carried out on 69 bakers working on both current and traditional baking processes, having a good ability to manage the process, and located all over France, to avoid any bias with regional practices. The questionnaire was designed together with experts on the basis of the succession of operations proposed by Roussel and Chiron (2002): mixing, first rising, dividing, rounding (making-up), relaxation, shaping, final proofing, scoring and baking. Because we already knew this standard process, we could send a closed questionnaire, in order to spare time (15 mn for answering), given the working load of the bakers.

2.2 Formulation at pilot scale: ingredients and breadmaking process follow-up

Flour (Protein 12%) Brasseuil T65 type was a gift from Moulins Giraudeau (44), it contained 12% water (total basis). It was mixed with 66% water (weight/weight flour) in mixer with oblique arm (Mahot) for 12 mn at 80rpm to obtain 3 kg dough. Necessary adjustments were made to yeast content in order to modify density. 7.5% wheat fibres (fine bran, namely "shorts") were incorporated in order to get a ash level equivalent to a T80 type flour. To obtain bread in the format "baguette", two processes were applied: current French bread (PCF) and traditional French bread (PTF), the latter mainly having longer proofing times. The target specifications and properties are recalled in table 1.

Table 1: Target characteristics and properties of bread "baguettes" and symbols used in figures.

| Sample # | Symbol | Type & composition | Density | Main Target Features |
|----------|--------|----------------------|---------|---|
| 1 | □ | PCF | 0.18 | « Blank » high GI |
| 2 | ■ | PCF+fibres | 0.20 | Regular crumb grain T80 |
| 3 | □ | PCF « dense » | >0.3 | High density, regular crumb grain |
| 4 | ○ | PTF | 0.25 | Irregular crumb grain |
| 5 | ● | PTF+fibres | 0.25 | Irregular crumb grain T80 |
| 6 | ● | PTF+ modified fibres | 0.25 | Id. |
| 7 | ● | PTF+fibres « dense » | 0.35 | High density, irregular crumb grain T80 |
| 8 | ○ | Sourdough bread | 0.35 | High density, irregular crumb grain |

During proofing, the section and shape of dough were continuously measured by camera video (every 5mn) and image analysis in order to determine the evolution of dough porosity, assuming cylindrical symmetry, and dough stability, defined by the ratio height/maximum width (H/L). Breads (baguettes) were baked in a Bongard traditional electric deck oven (V=200L, P=21kW) at 250°C for 26 mn.

2.3 Study at lab scale: structural and texture analyses

For α -amylolysis, bread pieces ($\approx 0.25\text{cm}^3$) are stirred within flaks containing 150mL water and $.01\mu\text{g}$ amylase (ref 1.163.12, Merck) /mg starch in phosphate buffer to reach pH7, at 37°C. 2mL of suspension are removed every hour for the first seven hours and then at 24 and 28h; hydrolysis products (oses, oligosaccharides) are measured after centrifugation according to the procedure detailed by Tollier and Robin (1979). All measurements were triplicated, leading to a relative uncertainty <5%. Initial velocity and starch easily degradable fraction are determined after fitting amylolysis curve according to a pseudo 1st order kinetic model, in order to be compared to results from *in vivo* clinical assays (Rizkalla *et al.*, 2005). Thermal and mechanical analyses of dough were performed by DSC and DMA as described in detail by Chevallier *et al.* (2000) in order to assess starch gelatinization and gluten aggregation under conditions as close as possible of baking process (heating rate $\approx 5^\circ\text{C}/\text{mn}$). The shear behaviour of unleavened doughs was studied by adapting creep-recovery tests on plane/plane shear rheometer

according to Rouille *et al.* (2005). Crumb grain (texture) was assessed by scanning (800dpi) about 10 slices x 3 baguettes per sample; the images were analysed, using Aphelion and MatLab softwares, and, following canonical analysis, similarity maps were drawn to compare crumb grain, detailed procedures being adapted from Lassoued *et al.* (2007). Overall mechanical properties of baguette pieces are determined by multi-indentation test early set-up to assess crust crispness and crumb firmness by applying a compression/relaxation test with 10 to 20 adjustable pins, from force-displacement curve as described in details by Chaunier *et al.* (2008).

3. Results and discussion

3.1 Nutritional properties : glycemic indices and starch modifications

Like for heat moisture treated starchy products, the kinetics of amylolysis of breads were comprised between those of native starch (low accessibility of enzyme) and extruded starch (easily accessible) (Fig.1a). Although significantly different, their similar shape allowed them to be fitted by the equation:

$$(\% \text{ hydrolysis}) = a \cdot \text{Log} (1 + t/b) \quad (1)$$

t (h) being the time of hydrolysis, and the initial velocity $V_0 = a/b$ can be used to compare with values of *in vivo* glycemic index (Fig.1b).

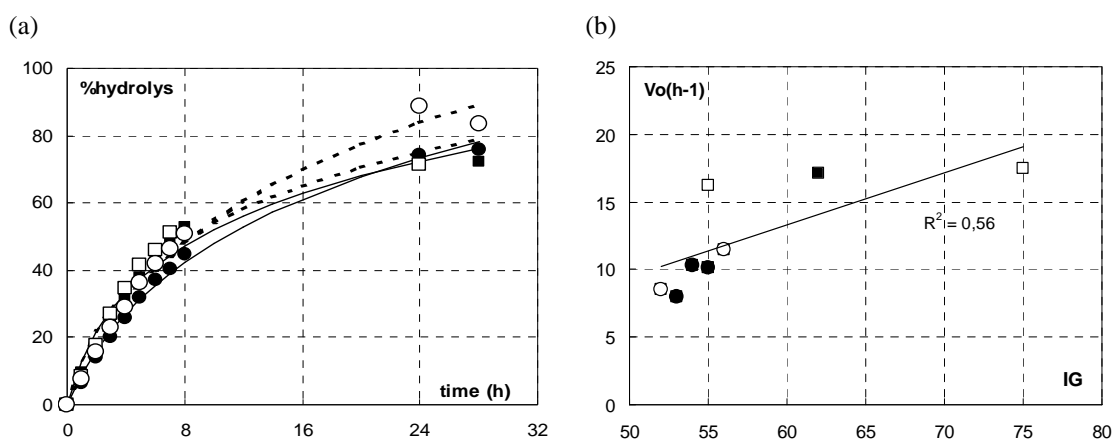


Figure 1 : Results of kinetics of amylolysis for (a) breads without (1,4: □,○) and with fibres (2, 5 : ■,●) and their fit (dotted= without, full=with fibres) with eq.(1) and (b) comparison of initial hydrolysis velocity V_0 with *in vivo* IG (full legend in Table 1).

Given the error values, comparison between kinetics shows that bread glycemic index does not depend first on the DF content but that is rather influenced by the breadmaking process, since all traditionally processed breads have lower IG (<60%) and V_0 values (<12h⁻¹). Results from amylolysis, namely V_0 , are just fairly correlated with *in vivo* IG results. This is not surprising, since human digestion involves more phenomena including mastication and gastric emptying that even more sophisticated *in vitro* methods (Englyst *et al.*, 1999) do not address, but at least, amylolysis gives a first mean of screening and relating nutritional properties to starch structural modifications. Regarding these latter, DSC results showed that in the crumb, starch was completely gelatinized whereas in the crust, the presence of fibres might have reduced this modification. The first result may be explained because the curve of moisture/temperature within bread (in the crumb) during baking (Wagner *et al.*, 2007) early crosses the melting curve of starch; conversely, the uncertainty on the variations of temperature and moisture at bread surface (crust) limits the interpretation of the role of fibres during baking.

3.2 Bread texture: mechanical properties and crumb appearance

The acquisition and analysis of images from bread cross sections allow to draw a similarity map of the crumb grain, or visual appearance, where the ellipses represent the variability along the baguettes (Fig. 2a). When not overlapping, their location suggests that the main effect of process is that traditional bread has a coarser cellular structure with larger void cells than current one and that fibres addition increases

crumb homogeneity and density. However, resulting from multi-indentation measurements, apparent modulus E (Pa) and residual stress σ_s (Pa), likely accounting for crust and crumb mechanical properties respectively, are well correlated (Fig. 2b). This result suggests that neither the process nor the addition of fibres modify the texture contrast of “baguettes”.

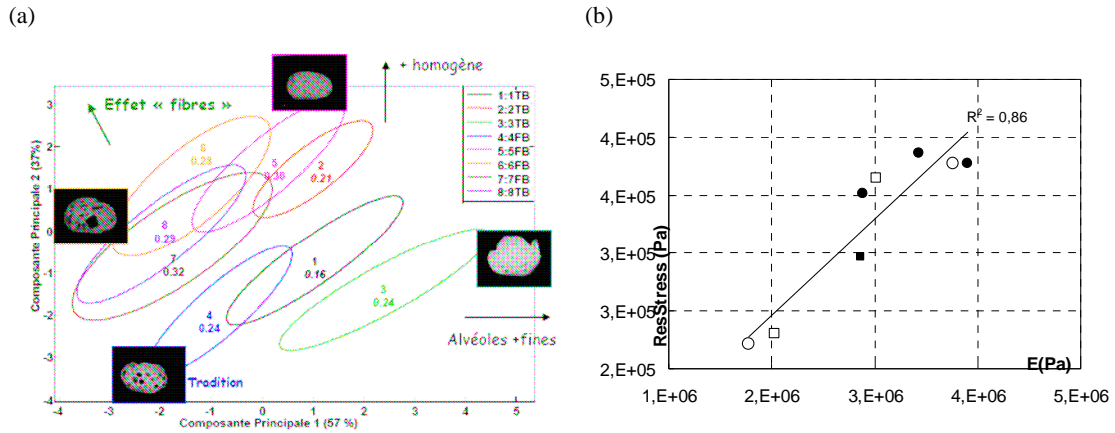


Figure 2 : Texture of baguettes defined by (a) the similarity map of baguette crumbs and density and (b) the variations of their mechanical crust/crumb properties (same legend as Fig.1)

When compared with the results obtained in studying consumer’s acceptance (Martin et al., 2008), the addition of fibres to traditionally processed bread may seem a good opportunity to cope with sensory requirements.

3.3 Integration of practical knowledge in processes

The results of the survey on bakers’ professional practices underline the significance of two main operations, on which rely the variability of the processes of breadmaking: proofing and dough making-up.

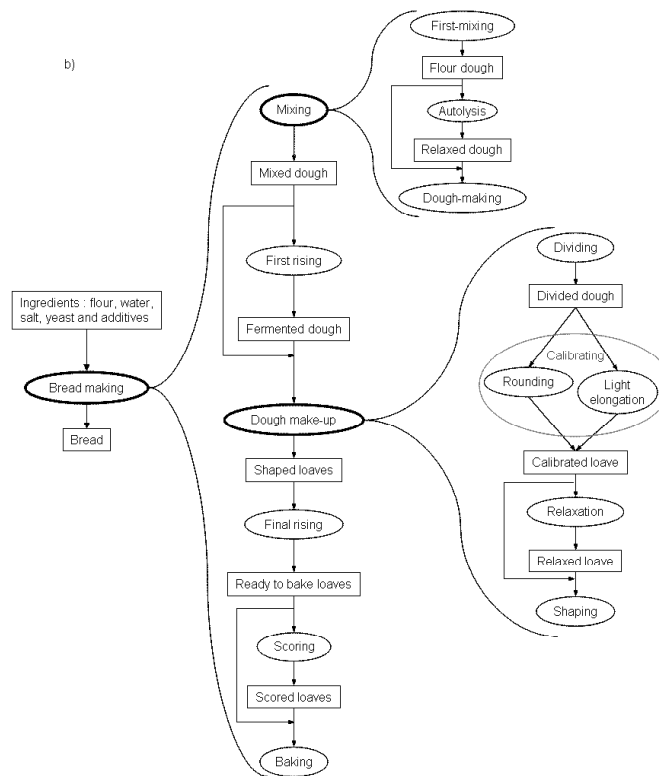


Figure.3: Flow sheet of the unit operations of breadmaking process after crossing with the results of the survey. Ellipses are unit operations and rectangles define dough states.

Actually, these two operations may not be conducted under a wide range of conditions but the different sequences in which they can follow each other reflect the craftsmen's expertise. As represented in Fig.3, this diversity allows to complete the diagram early drawn by Roussel and Chiron (2002). Conversely, mixing may involve a wide range of operating conditions and equipments but only occurs once, as a starting operation. The main mechanisms of change in dough structural features occurring during these operations are linked to dough fermentation and deformation, and they are empirically assessed by the craftsmen using various sensory criteria named: development, stability and consistency, toughness, smoothness, respectively. Therefore, a close attention was devoted to these phenomena in order to relate sensory criteria to physical variables measured at lab scale.

3.4 Dough behaviour

From the follow-up of dough development during fermentation, no significant influence of fibres addition was found for the evolution of porosity. The evolution of this property followed a classical sigmoid curve (Romano *et al.*, 2007), with an inflection point close to (30mn, 40%) in both cases, with and without fibres. However, they did not display the same stability, as shown by the curves $H/L(t)$ and the images of dough at the end of proofing (Fig. 4a). In most cases, these curves can be well fitted ($r^2 > 0.95$) by an exponential decay, for time values ≤ 90 mn:

$$H/L(t) = [(H/L)_0 - (H/L)_\infty] \cdot \exp(-t/t_c) + (H/L)_\infty \quad (2)$$

in which $(H/L)_0$ and $(H/L)_\infty$ feature the initial and long term values of stability, resp., and t_c the stability characteristic time.

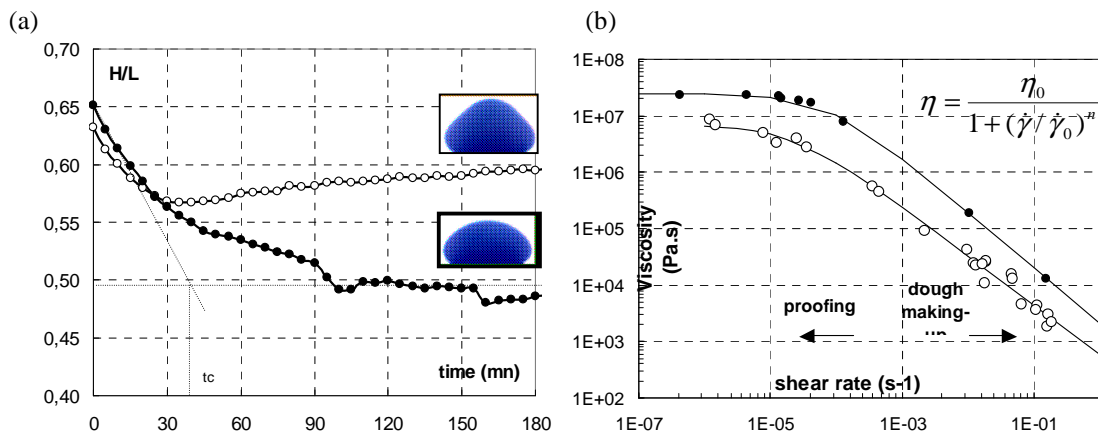


Figure 4: curves of behavior (a) of stability and images during proofing and (b) of flow under shear (viscosity vs shear rate) for doughs with (●) and without (○) fibres.

The flow curves of the dough could be fitted by the Cross model (Fig.4b), inserted in the graph. The increase of viscosity due to the addition of fibres, mainly at lower shear rate value ($\approx 10^{-4} \text{ s}^{-1}$), may be attributed to a reinforcement of the dough due to the addition of solid particles or to the decrease of water in the viscoelastic gluten network (Rouillé *et al.*, 2005). It may be the cause of the loss of stability of the fibres-enriched dough by precluding upwards bubbles migration or by destabilizing the interface between gas bubbles. These phenomena control the acquisition of cellular structure, and crumb texture. Finally, for higher shear rate values, the viscosity difference is less significant but suggests that higher mechanical power is required during mixing and making-up.

4. Conclusion: process recommendations and prospects

Taking into account these results as well as our expertise in breadmaking reflected in Fig.3, it is suggested that when incorporating fibres, (1) the level of hydration of the dough is slightly increased (+3% total weight) in order to decrease dough viscosity, and (2) the total proofing time is decreased (-15mn) to reduce the loss of stability. As expected, the consequence is that the density of dough before baking, and hence, its final value, is increased. The resulting breads well illustrate this trend (Fig.5a), but the influence of breadmaking process is also significant. This increase of density is particularly important as it seems to

govern texture, by increasing modulus, in a similar way as Gibson-Ashby's model allows to predict the mechanical properties of cellular solids (Zghal and Scanlon, 2001). The role of density is as much important as its increase leads to a decrease of *in vivo* glycemic index (Fig.5b). This increase of density may be explained either by a limited starch destructureation caused by a decrease of thermal flow within dough during baking, in agreement with Wagner et al. (2007), or by a reduced bread fragmentation during chewing, which further hinders the accessibility to enzyme during digestion (Zghal and Scanlon, 2001).

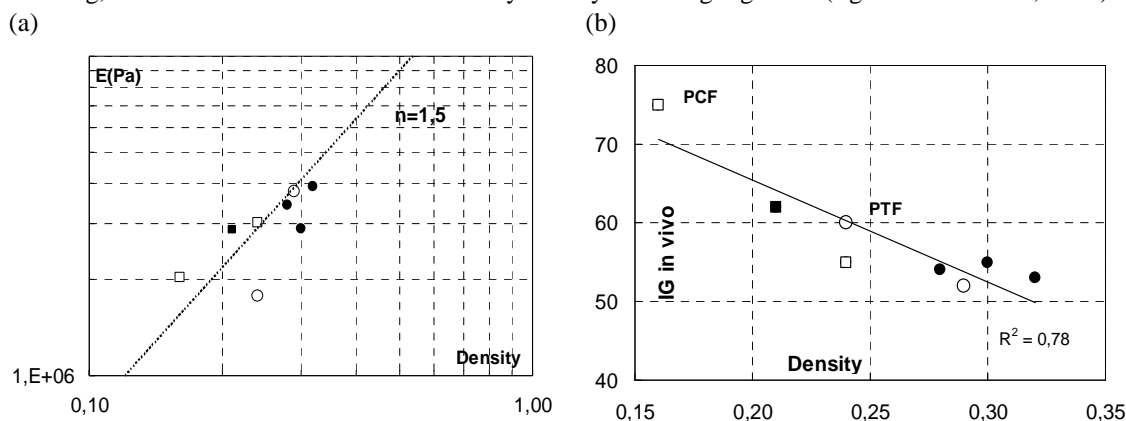


Figure 5: Variations with density of (a) crust/crumb apparent modulus (dotted line = Gibson-Ashby's power law) and (b) *in vivo* IG (same legend as Fig.1).

As DF addition is thought to affect the structural changes during baking (starch gelatinization, gluten aggregation ...), there is a need to elucidate the link between bread density and IG. Conversely, due to its interest for nutritional purposes, most results may be transferred as guidelines for incorporating dietary fibres in breadmaking.

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