Journal of Food Engineering 203 (2017) 6–15

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Quantitative MRI study of layers and bubbles in Danish pastry during the proving process

Cécile Deligny [a, b], Guylaine Collewet [a, b], Tiphaine Lucas [a, b, *]

[a] Irstea, UR OPAALE, 17 Avenue de Cucillé-CS 64427, F-35044, Rennes, France
[b] Univ Bretagne Loire, France

ARTICLE INFO

Article history:
Received 13 October 2016
Received in revised form
12 January 2017
Accepted 16 January 2017
Available online 18 January 2017

Keywords:
Dough
Fat
Puff pastry
Inflation
Bubble
Gas cell

ABSTRACT

Proving of a real sized Danish pastry (10 cm × 5 cm) was studied by MRI to visualize dough and fat layers and their evolution. The number of fat layers was varied from 4 to 12, the latter being relevant to the lower range used on an industrial scale. A new method of quantification of the three components, gas, gas-free dough and fat, in partial volume was applied to MRI images of Danish pastry during proving. The method estimated accurately the proportion of gas with a maximal bias of 5%. Sheeting steps up to 3 did not modify the inflation process of pastry and hence did not alter the gluten network and its capacity to retain gases at the global scale. A degassing effect of lamination was observed from the third sheeting step (dough layers with median thickness of about 750 μm). Thickness between dough layers was not the same from the bottom to the top of the laminated dough and this was amplified during proving. However, the gas proportion in these layers was homogenous and there was no effect of the position of the layer on its expansion. Large bubbles (> 0.5 mm) were visualized in dough layers but they were not elongated at this step of processing, as are bubbles typical of Danish pastry once baked. Eye-shaped bubbles were instead visualized in fat layers; their number increased more rapidly than that of fat layers. They contributed to less than 10% of overall inflation. Finally, large, undetectable portions of fat (40 ± 13 mm equivalent to about 80 pixels) were assigned to missing fat material and breaks in the layering, considered as undesirable by the bakers. These void spaces represented 7.7% of the expected total length of fat layers in the MRI images, a proportion also reported from CLSM images of the same pastries.

1. Introduction

Puff and Danish pastry is characterized by a unique original baked alveolar structure with large, irregular bubbles nearly always distributed horizontally, which provides a typically light and flaky texture. This structure results from alternating thin layers of fat and dough formed by successive folding and sheeting steps. The high capacity of expansion (400–700%) is another particular feature of such bakery products, highly dependent on the number of fat layers (McGill, 1975; Gerrard et al., 2000; Deligny and Lucas, 2015). From a mechanistic point of view, the fat layers in puff pastry are intended to act as impervious barriers against the water vapor produced from dough upon heating, and to force each dough layer to expand due to the pressure developed beneath each impervious layer (McGill, 1975; Kazier and Dyer, 1995). This property of barrier function is thus conditioned by the continuity of the fat layers after the last sheeting step. While the number of folding and sheeting is increased in a view to increasing the number of impervious layers, it also favors the fat fragmentation and hence the discontinuity of the fat layers. Lift during baking is usually enhanced by a higher number of fat layers, up to a point where fat is too fragmented to ensure its barrier function (McGill, 1975).

Most reports, dating from the 70's-90's and dedicated to puff pastry, focused on the dimensions of the finished product. Indeed, like many bakery products, the alveolar structure of puff and Danish pastries is fragile and may collapse if intrusive measurement techniques are used during processing. Pictures of baked alveolar structures were more rarely reported, and still lacked quantitative analysis (Cauvain and Telloke, 1993; Filloux, 2008; Deligny and Lucas, 2015). Recent advances in the techniques of imaging and image analysis offer new opportunities for capturing the structural elements in bakery products together with their changes during processing; this opens up the possibility to re-

---

* Corresponding author. Irstea, UR OPAALE, 17 Avenue de Cucillé-CS 64427, F-35044, Rennes, France.
E-mail address: tiphaine.lucas@irstea.fr (T. Lucas).

http://dx.doi.org/10.1016/j.jfoodeng.2017.01.016

explore the mechanisms governing expansion in these kinds of product (Grenier et al., 2003; van Duynhoven et al., 2003; Bellido et al., 2006; Lucas et al., 2010; Altamirano-Fortoul et al., 2012; Chakrabarti-Bell et al., 2014; Van Dyck et al., 2014).

In this study we focused on the proving step, specific to Danish pastry, and tomography so to capture the picture of the real-sized product. Both the pixel size and the signal contrast between dough and fat are crucial characteristics of image acquisition for getting an appropriate picture of the internal structures of laminated dough and are hence further discussed below. On the one hand, the large dimensions of the object to be imaged represent a limit to highly resolved images; this statement applies whatever the imaging modality (X rays or MRI, Magnetic Resonance Imaging). For a typical dimension of 10 cm, and a 256 × 256 matrix, the pixel size will be about 400 μm. Decreasing the pixel size below this value will deteriorate the signal to noise ratio in the image (yet not very high due to the low density of dough —as well as the fast relaxation of water protons in dough for MRI). This situation is counterbalanced with high anisotropy of the pixel, setting a much larger slice thickness for the image (3–10 mm) than the resolution in the plane of the image. At this pixel size, fat layers in laminated dough are likely to be partially resolved by tomography, resulting in partial volume effect (pixels containing both fat and dough). Indeed, fat layers in Danish pastry are usually much thinner than dough layers, because of the lower initial proportion of fat in the “primary book” —around 130 and 60 μm for 8 and 16 fat layers respectively versus 800 and 400 μm for dough layers just after lamination (Bousquières et al., 2014a). The same partial volume effect applies to the smallest bubbles in the dough layers (pixels containing both gas and gas-free dough). Size of gas bubbles is below 300 μm just after mixing (Bellido et al., 2006) and 25–50% of bubbles in number remain below this threshold at the end of proving (Babin et al., 2006). This explains why former tomographic studies dedicated to bread dough proving focused on the largest sized bubbles (>1 mm^2 in section), (e.g. van Duynhoven et al., 2003). On the other hand, the difference in signal for bound water and fat protons in foodstuffs is high enough whatever the tomographic modality; in food applications, this allowed the direct or indirect quantification of fat in meat for classification purposes (e.g. Collewet et al., 2013). The exact proportion of each component in each pixel presenting partial volume can also be easily unraveled in the case of binary mixtures (e.g. Collewet et al., 2013) for MRI. Indeed, in this case, the number of unknowns in each pixel is two. Together with the sum-to-one constraints of the proportions, one image is theoretically sufficient to estimate these unknowns. However, in the case of ternary mixtures, one image is no longer sufficient to unravel the contributions of each component. While X-ray provides only one image (Artz et al., 2012), MRI imaging can provide multiple images with different contrasts (T_2, T_1 or density weighted images) and was used for the present study dealing with a ternary mixture of fat, gas and gas-free dough (only water protons in tight interaction with macromolecules give signal from this last component).

The aim of the present study was to characterize with MRI the proving process of Danish pastry (10 cm × 5 cm). Laminated dough was prepared with 4–12 fat layers, the latter being relevant to the lower range used on an industrial scale (Cauvain and Telloke, 1993). A MRI-based method, referred as the “mapping method” in the sequel, was developed to calculate the proportions of gas, gas-free dough and fat inside each pixel of the MRI image of laminated dough. The first objective was to analyze the gas proportion at different scales, that of the laminated dough sample (a few centimeters), that of dough layers (from 0.1 to 1 mm) and that of the individual bubbles (for the largest ones). At the scale of the laminated dough sample, the effect of the number of fat layers on the total gas proportion was studied and the initial gas proportion was particularly used for evaluating the degassing function of lamination with the increasing number of sheeting steps. Shear extent is expected to depend on the distance of the dough layer to the roller, with an expected impact on the gluten network and the later gas retention. This was inspected through gas proportion calculated in each dough layer. Finally, it was also hoped to visualize the presence of the large, eye-shaped or elongated bubbles typical of Danish pastry, at least at the end of proving. The second objective was to better characterize the morphology of fat layers despite the partial volume effect in the MRI image. Thickness of fat layers and large voids in fat layers were measured in fat proportion maps and compared to CLSM measurements (Bousquières et al., 2014a,b) earlier performed with the same preparation of laminated dough but at higher spatial resolution and smaller field-of-view (3.9 mm × 5.7 mm) than MRI.

2. Materials and methods

2.1. Preparation of samples

The procedure for preparing the Danish pastry was previously reported in Deligny and Lucas (2015). In the current work, laminated dough is a shorthand name referring to the result of the lamination process with alternating fat and base dough layers. Four and 8 fat layers were obtained by two-fold turns applied twice and three times, respectively. Twelve fat layers were obtained by a three-fold turn applied to a paste sheet with 4 fat layers. These numbers of fat layers are referred to in the current work; note that under the conditions of paste preparation used in this study, the real number of fat layers is in average 7% lower than the theoretical value (Bousquières et al., 2014b). Just before proving inside the MRI probe, optical fibers were placed in the laminated dough sample (10 cm × 5 cm) and the atmosphere of the MRI device was controlled at 30 °C (±1 °C) under humidity close to saturation. Optimal proving duration for this recipe was 180 min accordingly to industrial practices; proving was prolonged for the interest of the present study. Further details about the MRI device can be found in Lucas et al. (2010). The whole experiment was repeated three times for each number of fat layers.

In a specific experiment, base dough was not laminated but sampled just after mixing and was gently sheeted down to 7 mm thick to avoid degassing. A rectangle (10 cm × 5 cm) was cut from the center of the dough sheet and placed in a plastic container for proving. It was placed immediately inside the MRI probe and continuously monitored. Since the yeast activity is temperature- and time-dependent, the same thermal history as that of the laminated dough was applied to the base dough with the aid of a temperature-controlled device placed inside the MRI probe. For this purpose, each step of the paste processing has been previously characterised by duration together with an average temperature or a constant rate of heating/cooling. The section of base dough was measured as described in section 2.3.2.

2.2. MRI measurements

2.2.1. MRI

MRI monitoring of laminated dough proving was performed with a Siemens Avanto 1.5T, equipped with a “knee antenna”, and using a spin-echo sequence with two so-called “echo times” (TE 7 and 32 ms) to get two images with different contrasts. The other parameters were as follows: TR 400 ms, pixel side 0.5 mm, slice