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Characterisation of structural patterns in bread as evaluated by X-ray computer tomography

T. Van Dyck [a,b,*], P. Verboven [a], E. Herremans [a], T. Defraeye [a], L. Van Campenhout [b], M. Wevers [c], J. Claes [b], B. Nicolaï [a]

[a] BIOSYST-MeBioS, University of Leuven, Willem De Croylaan 42, B-3001 Leuven, Belgium

[b] Lab4Food, Faculty of Engineering Technology, Department of Microbial and Molecular Systems, Leuven Food Science and Nutrition Research Centre (LFoRCe), Kleinhoefstraat 4, 2440 Geel, Belgium

[c] Department of Metallurgy and Materials Engineering, University of Leuven, Kasteelpark Arenberg 44, B-3001 Leuven, Belgium

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ABSTRACT

X-ray micro-tomography and a volume stitching strategy were combined to create a high resolution 3D image of entire cross sections (slices) of bread. Morphological analysis of whole slices revealed structural properties on a product scale. The addition of wheat bran yielded a lower loaf volume, higher structure thickness and a higher number of closed pores, while maintaining a similar porosity to its no-bran counterpart. Freestanding bread loaves had a higher loaf volume, a lower structure thickness and a higher porosity than pan baked bread. Remarkably, variations between batches of each type of bread were found to be rather small when judging them by these parameters. In addition, localized morphological analysis was applied to generate spatial maps of the porosity, the structure thickness and the number of closed pores on the cross sections of bread. This provided insight into the heterogeneity of bread, revealing localized microstructural features/defects, molding lines, crust artifacts and effects of baking kinetics. Analysis of porosity distributions revealed very significant differences between all samples and the standard deviation of these distributions proved to be a good measure for the heterogeneity across a slice of bread.

1. Introduction

The microstructure of bread determines its texture, visual and sensory properties and, hence, has a strong effect on consumer acceptance (Dijksterhuis et al., 2007). A better understanding of the microstructural features of bread thus allows to improve its quality and consistency as well as the development of novel bread formulations such as those aiming at an increased intake of dietary fibre. The addition of fibre to bread is, however, known to have negative effects on the quality of the product. Among these effects are a reduced loaf volume, increased loaf firmness and a reduced fermentation tolerance (Lai et al., 1989). These property changes have been linked to changes in the rheological properties of the dough (Wang et al., 2002), which in turn can be attributed to the fibre interfering with the formation of the gluten network (Rosell and Foegeding, 2007). Though many studies have focused on the addition of different types and size fractions of fibres (Zhang and Moore, 1999; Seyer and Gelinas, 2009; Curti et al., 2013), no research has focused on quantifying the effect of bran on the microstructure of a bread loaf.

With the introduction of synchrotron and micro focus X-ray computed tomography (micro-CT), high resolution imaging of foods in three dimensions has become possible (Herremans et al., 2013; Mendoza et al., 2007; Verboven et al., 2008; Lim and Barigou, 2004; Bellido et al., 2006). This technique is of particular interest for cellular materials such as bread, since the contrast between air voids and the solid phase is very high. Methods were developed to characterize bread quality by creating three-dimensional reconstructions from two-dimensional projections and performing morphological analyses (Falcone et al., 2006; Lim and Barigou, 2004; Perez-Nieto et al., 2010).

Subsequent studies on bread and related products used morphological parameters to describe the structure at a micrometre scale. These results have been used to explain the effect of production parameters, like proving conditions (Primo-Martin et al., 2010), flour quality (Wang et al., 2011), steaming (Le Bail et al., 2011; Altamirano-Fortoul et al., 2012) and the effects of storage (Luyten et al., 2004). Both crust and crumb have been studied in their own right and the use of sample sizes of only several millimetres allowed for a detailed description of their structure. However, in trying to establish a link between these structures and the functional properties of bread, the problem arises of extracting representative crumb specimens from a loaf which, in itself, may have a high spatial variability.

* Corresponding author at: BIOSYST-MeBioS, University of Leuven, Willem De Croylaan 42, B-3001 Leuven, Belgium. Tel.: +32 14 56 23 10; fax: +32 14 58 48 59.
E-mail address: tim.van.dyck@khk.be (T. Van Dyck).

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Recent investigations have tried to take this spatial variability into account by determining a porosity profile across the crust/crumb interface (Altamirano-Fortoul et al., 2012), by describing morphological parameters at discrete locations in a bread (Wang et al., 2002), or by a combination of these two methods (Besbes et al., 2013). Despite these efforts, a continuous overview of the spatial distribution of a concise set of morphological parameters across an entire loaf of bread is lacking. The absence thereof implies a lack of comprehensiveness when trying to link the data presented in literature to a real world product.

The current study presents a novel method, based on micro-CT imaging, to bridge the gap between high-resolution imaging of bread structure and sample sizes that are relevant for bread products. The method was applied to study the spatial variability within a sample as well as the effect of the addition of wheat bran on bread microstructure. Micro-CT imaging was applied to whole cross-sections (slices) of white bread, half wheat bread and whole wheat bread. Morphological analysis was used to calculate microstructural features that are mapped on the bread loaf to study the spatial variation of its microstructure.

2. Materials and methods

2.1. Samples

Bread loaves were produced by a local bakery. Four types of bread were used for the experiments: pan baked white bread, pan baked half wheat bread, pan baked whole wheat bread and free standing white bread. The composition of the base white flour as provided by the supplier was 11.4% protein (dry mass (d.m), N × 5.7), 0.55% ash (d.m.), 14.5% moisture and a Hagberg number of 240. 50% and 100% of the bran fraction, separated after milling, was added to the base white flour for half wheat flour and whole wheat flour, respectively.

Farinograms recorded for the three types of flour showed a water uptake of 55%, 58% and 63% at 500 Brabender units for white, half wheat and whole wheat flour, respectively.

Dough was prepared using 1000 parts flour, 30 parts compressed yeast, 17 parts salt, 60 parts sugar and 550, 580 or 630 parts water (depending on flour type). These ingredients were mixed in a spiral mixer for 5 min at low speed (140 rpm spiral speed, 12.8 rpm bowl speed) and 7 min at high speed (280 rpm spiral speed, 25.5 rpm bowl speed). After mixing, the dough temperature averaged 26 °C. The dough was allowed to rest for 20 min after which it was divided into portions of approximately 450 g. These portions were proved at 32 °C and 95% RH for 15 min. Each portion was molded manually to either an elongated shape, for pan baked bread, or a round shape for free standing bread. The dimensions of the pan baked loaves were 200 mm (length l) × 110 mm (width w) × 120 mm (height h); those of the free standing loaf were 200 mm (diameter d) × 110 mm (h). The final proof lasted 50 min (95% RH). The breads were baked at 210 °C for 35 min. The batches were prepared in large quantities (25 kg of flour) according to the regular daily production scheme of the bakery. One sample loaf was selected from these batches on three different days, providing three repetitions for each type of bread.

2.2. Sample preparation

Three different cross sections (slices) were cut from pan baked bread in order to have a view of the bread along its three axes/cutting planes. Fig. 1a displays a schematic showing the three cross sections relative to the loaf. Note that each cross section was cut from a different loaf. These samples were referred to by their respective cutting plane (XY, XZ, and YZ). Under the assumption of axial symmetry, only one cross section was cut from the free standing white bread (Fig. 1b). The thickness of the slices was 20 mm, which is considerably larger than the dimensions of the representative elementary volume for morphological analysis (see Section 2.3.4.2). The samples were cut using a regular bread knife, in combination with a custom support rig to ensure perpendicular and parallel cutting planes.

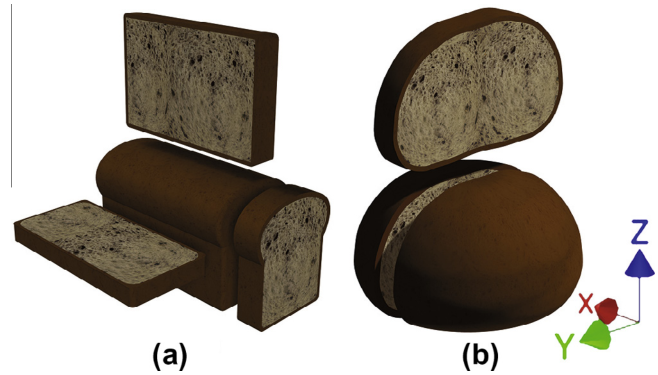

Fig. 1. Schematic of the cross sections taken from the pan baked (a) and free standing breads (b).

After cutting, each sample was placed in the centre of a cylindrical airtight plastic box to prevent dehydration and was stored in a room at constant temperature until the time of measurement with the CT scanner. The remainder of the bread from which the samples had been cut was placed at the bottom of the plastic box to help saturate the atmosphere inside to the equilibrium relative humidity and thus prevent dehydration of the sample. Upon measurement, the box with the sample was placed inside the X-ray scanner. The box prevented dehydration of the sample during scanning and thus helped to avoid any mechanical stresses which would arise and cause the sample to move whilst being scanned.

2.3. X-ray computed tomography

2.3.1. Scan setup

X-ray CT scans were performed at a pixel size of 30 μm using a micro focus scanner (AEA Tomohawk CT using a Nikon metrology 160 Xi Gun set X-ray source, MTM, University of Leuven). The scans required an accelerating voltage of 75 kV and a current of 220 μA. A total of 32 frames were taken and averaged after each rotation step of 0.3° during the rotation of 180°. The resolution of the detector was 1Mpixel. These scans resulted in a set of 626 images, which were reconstructed into a stack of 1024 × 1024 × 1024 voxels using NRecon software (version 1.6.6, Bruker microCT, Kontich, Belgium).

The pixel resolution of 30 μm was slightly higher than what has previously been reported in literature for bread. Values ranged from 6 μm (van Dalen et al., 2007) to 22 μm (Besbes et al., 2013). This resolution was however sufficient since the morphological parameters were similar to those obtained with scans performed at 12.3 μm resolution for the same type of bread (results not shown).

2.3.2. Scan pattern

The scan setup, as described above, allows a volume of 20 × 20 × 20 mm to be scanned. In order to scan a complete bread slice, multiple scans had to be performed for each slice. Fig. 2a illustrates the scan pattern that was used. The scans were performed with an overlap relative to each other. After each scan, the bread slice was moved along one axis, while the centre of rotation remained fixed relative to the X-ray source and detector.