3-D Imaging of Foods Using X-Ray Microtomography

Gerard van Dalen, Han Blonk, Henrie van Aalst, Cris Luengo Hendriks

The microstructure of food products determines to a large extent the properties of these products. A broad range of imaging techniques is available to the food researcher to image a wide range of microstructure elements. This paper describes the 3-D imaging, visualisation and analysis of food products using X-ray microtomography (XRT). Examples are given for air bubbles in dairy products, herbs in fat and pores in rice kernels. XRT proved to be a very useful technique to image the 3-D microstructure of food products. XRT is complementary to other microscopic techniques used for food research. With XRT, a full 3-D image of large samples can be obtained (e. g. rice kernels with a length of 6 mm) with a resolution of about 6 µm.

Introduction

The microstructure of food products determines to a large extent the physical, textural and sensory properties of these products. Developing a proper understanding of the microstructure, particularly the spatial distribution and interaction of food components, is a key tool in developing products with desired mechanical and organoleptic properties [1]. Information about the 3-D microstructure of food products and ingredients can be obtained using various imaging techniques [2, 3, 4]. Commonly used techniques are bright-field, polarising and fluorescence light microscopy (LM), confocal scanning laser microscopy (CSLM) and electron microscopy (EM). Other techniques such as atomic force microscopy (AFM) and magnetic resonance imaging (MRI) are used for specific food applications. A relatively new technique is X-ray microtomography (XRT) which is mainly used for medical applications [5, 6]. XRT can probe the microstructure of samples non-invasively up to a few millimetres across with an axial and lateral resolution down to a few micrometers. The contrast in XRT images is based on the difference in absorption of X-rays by the constituents of the sample (e. g. water and air). XRT allows observations under environmental conditions without sample disturbing preparations that are normally used in LM and EM. This article presents the 3-D imaging of foods using XRT combined with 3-D visualisation and 3-D image analysis. Examples are given for three different food products.

Methodology

Samples were imaged using a Skyscan 1072 desktop XRT system (http://www.skyscan.be). A detailed description of the XRT system is given by Sasov e. a. [7]. XRT produces two-dimensional images of projections of the sample. A set of flat cross sections was obtained after tomographical reconstruction of images (1024 x 1024) acquired under different rotations over 180° with a step size of 0.45°. The acquisition time for one projection was 2.8 s resulting in a total acquisition and read-out time of about 40 min. Dairy and fat samples were imaged using plastic straws with an inner diameter of 2.9 mm. Rice kernels were fixed on a specimen holder using glue. The features in the stacks of 2D images were identified and measured using an image analysis toolbox (DIPlib, Delft University of Technology, NL) running under MATlab. For visualisation in 3-D space, isosurface rendering was used (Amira, TGS). This was mainly done by segmentation using thresholding followed by surface generation with constrained smoothing. The surface generation module of the Amira software computes a triangular approximation of the interfaces between the segmented section. In cases were no automatic segmentation was possible,

Keywords

X-ray microtomography, X-ray microscopy, XRT, foods, 3-D imaging

G.I.T. Imaging & Microscopy 03/2003, pp 18–21, GIT VERLAG GmbH & Co. KG, Darmstadt, Germany, www.imaging-git.com

segmentation was performed using the manual editor tools of the Amira software. To reduce noise a median filter with a size of 3 x 3 pixels was used.

Results

Air Bubbles in Dairy Products

Many food products, such as whipped cream, dessert toppings and mousses, are manufactured in the form of an emulsion and subsequently aerated to a foam. With these products, the protein present provides emulsion stability while the emulsifiers promote fat crystal agglomeration which forms a matrix. This matrix provides structure and firmness to the foam. Representative XRT images of cross sections of an aerated dairy sample are shown in Figs. 1a and 1b. The gas bubbles are clearly visible within the fat/protein/water matrix by their low grey value (low absorption coefficient). Figs. 1c and 1d show the results of the 3-D rendering. Gas bubbles near the edge of the sampling straw are deformed. The volume fraction of the gas bubbles, analysed from the total stack of 2-D images was 34 %. The size distribution of the gas bubbles is shown in Fig. 1e.

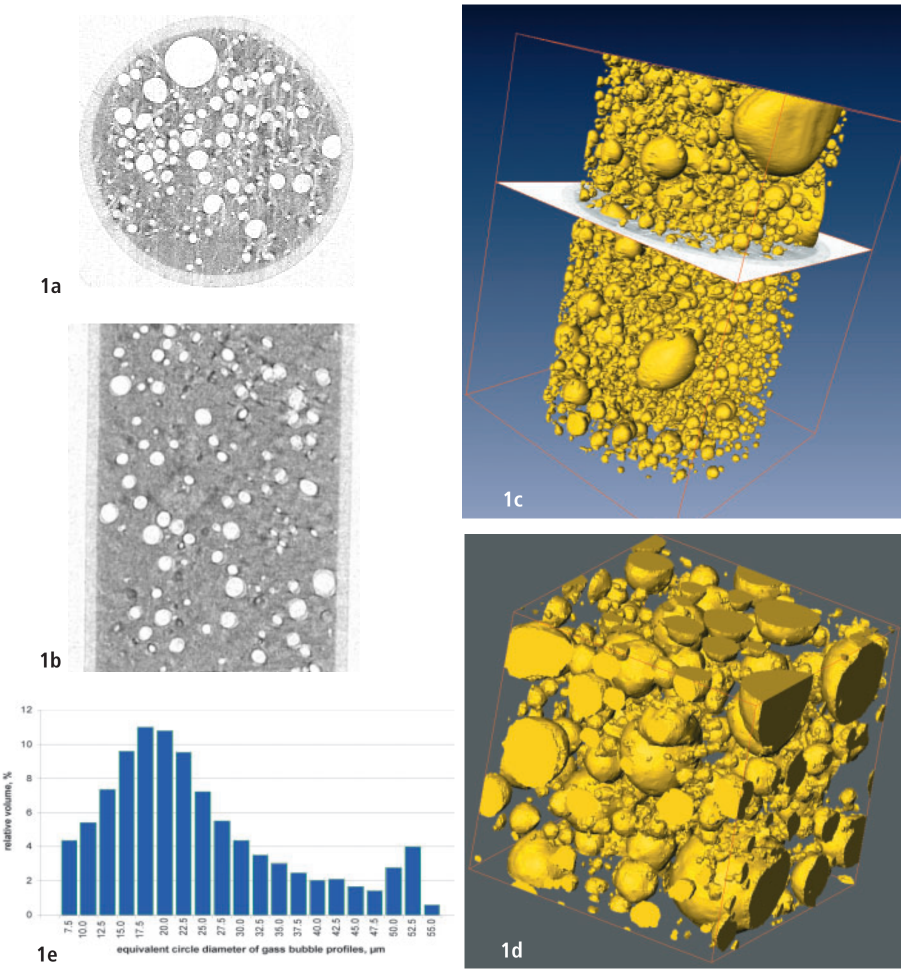

Fig. 1: XRT images of horizontal (a) and vertical (b) cross sections of an aerated dairy product with 3-D reconstruction of gas bubbles from 473 horizontal cross sections (c: box of 1.8x1.8x4.3 mm´s) with enlarged view (d: cube of 0.9 mm side), voxel size = 4.5x4.5x9.0 µm.
Fig. 1e : Size distribution of gas bubbles based on volume.

Herbs in Fat

Herbs, spices and dehydrated vegetables can be added to cooking fats and oils, e.g. as an ingredient of instant meals. To prevent separation, stabilisers are added to the fat. Stabilisers are partly or completely hydrogenated natural fats such as rapeseed. Figs. 2a and 2b show XRT images of cross sections of a fat sample containing herb particles and Fig. 2c the 3-D model of the herb particles reconstructed from 50 horizontal cross sections. The herb particles are clearly visible within the fat matrix by their high grey value (high absorption coefficient). They are homogeneously distributed in the fat matrix.

Rice Kernels

Rice is an important staple food for two-third of the world population. Its quality is based on a variety of properties such as texture, size and shape. Beside the generally used white milled rice, processing yields a large variety of rice product. For instance, puffed and popped rice used as traditional breakfast cereals and snack foods, precooked rice used for rice-based convenience food products and extruded rice flour for noodles, snacks and chips. XRT images of cross sections of a heat treated rice kernel are shown in Figs. 3a and 3b and 3-D

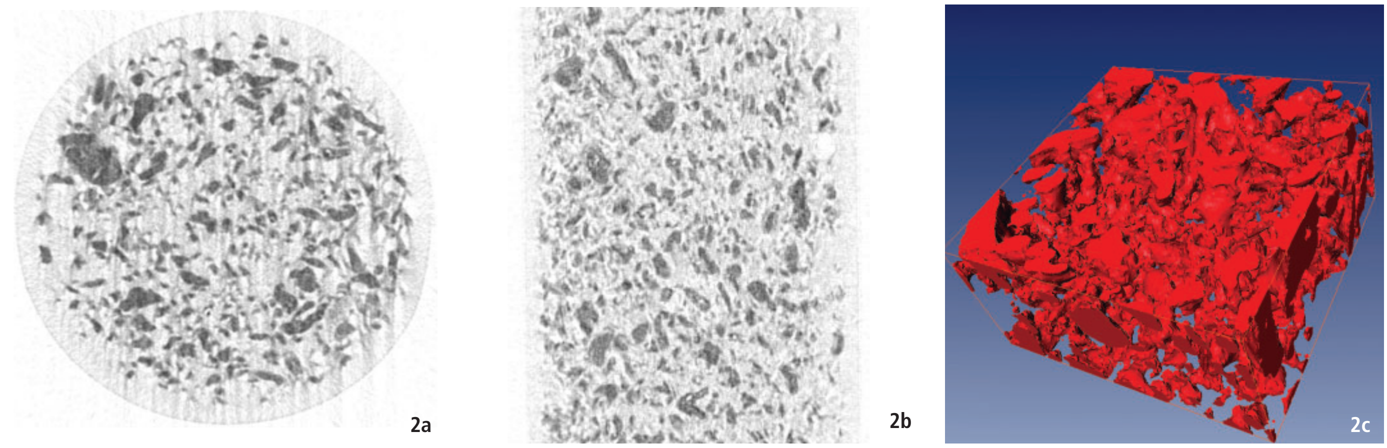

Fig. 2: XRT images of horizontal (a) and vertical (b) cross sections of a fat sample containing herbs with 3-D reconstruction of the herb particles (c: box of 1.1x1.1x0.55 mm´s), voxel size = 5.5x5.5x10.9 µm.

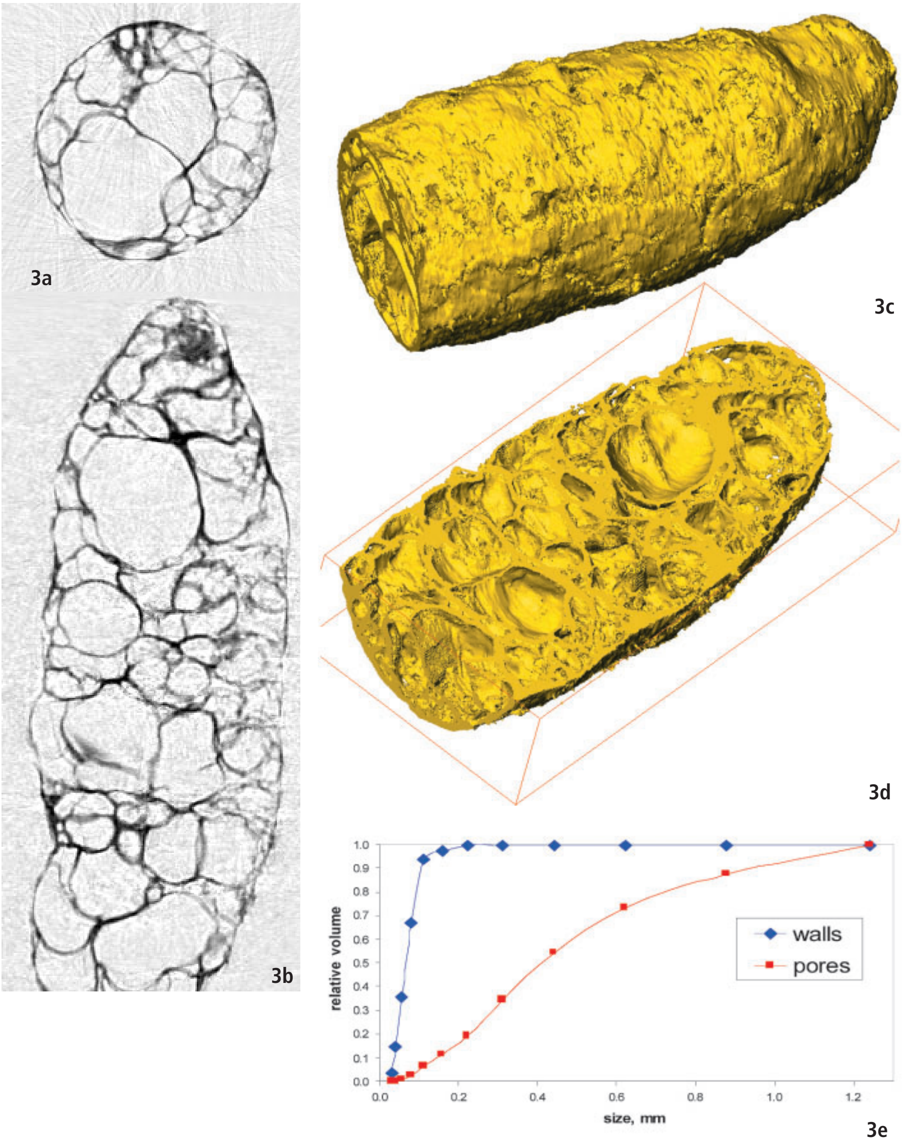

Fig. 3: XRT images of horizontal (a) and vertical (b) cross sections of a heat treated rice kernel with 3-D reconstructions of the surface (c) and interior (d) of the rice kernel reconstructed from 586 horizontal cross sections (box of 3.8x3.8x8.1 mm´s), cubic voxels of 13.7 µm.
Fig. 3e: Cumulative size distribution of the walls and pores of a heat treated rice kernel (size of morphological structuring element in mm).

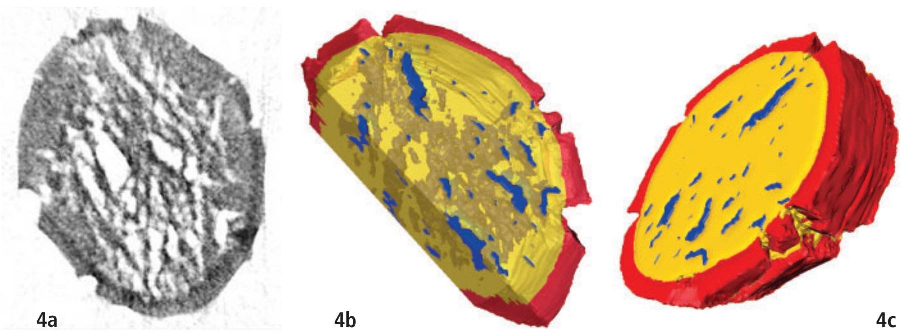

Fig. 4: XRT image (a) of a horizontal cross section of a heat treated rice kernel with 3-D reconstructions of the rice kernel (1.7x2.2x0.7 mm's) reconstructed using 40 horizontal cross sections (b: opaque, c: transparant and clipped). The dense outer layer is visualised in red and the pores in blue.

models of the rice structure in Figs. 3c and 3d. Large pores are visible within the rice kernel. They can be clearly distinguished from the starch matrix by their low grey value. The 3-D pore and wall size distribution was determined using morphological sieving [8, 9]. The procedure is applied on the grey-value images, avoiding the need for segmentation. Sieving involves morphological filtering at different scales (grey-value opening for the pore sizes and grey-value closings for the wall sizes). This yields a scale-space, from which a volume-weighted cumulative size distribution can be obtained (often referred to as granulometry). The results are shown in Fig. 3e. During heat treatment of rice, a dense outer layer can be formed, slowing down the uptake of water. This layer is visible in the XRT images by the lower grey value (see Fig. 4). An average thickness of 61 µm was measured for the outer layer shown in Fig. 4. XRT can be used to follow the change in microstructure during processing. An example is given in Fig. 5, showing the 3-D models of a rice kernel before and after cooking for 15 s. The influence of the water uptake on the pores is clearly visible. The orientations of the rice kernel before and after cooking are not identical because the kernel had to be removed for cooking and placed back for imaging again.

Conclusion

XRT proved to be a very useful technique to image the 3-D microstructure of food products. XRT is complementary to other microscopic techniques used for food research. With XRT, a full 3-D image of large samples can be obtained (e. g. rice kernels with a length of 6 mm) with a voxel resolution of about 6 µm. This in comparison to CSLM, allowing a voxel resolution of about 0.5 µm, however with a very limited depth of about 15 µm (for highly scattering food products) [4]. XRT allows visualisation and image analysis of the full 3-D microstructure, measuring the size, shape, networking/connectivity and distribution of various phases. These measurements will represent the full 3-D microstructure, which is not always possible by 2-D image analysis using statistical techniques. This is in particular the case for channelling and network phenomena. Combined visualisation of the microstructure using XRT and other microscopic techniques, extraction of quantitative data obtained by image analysis, and modelling of the microstructure based on characteristics of the structuring elements should point to the optimal food product.

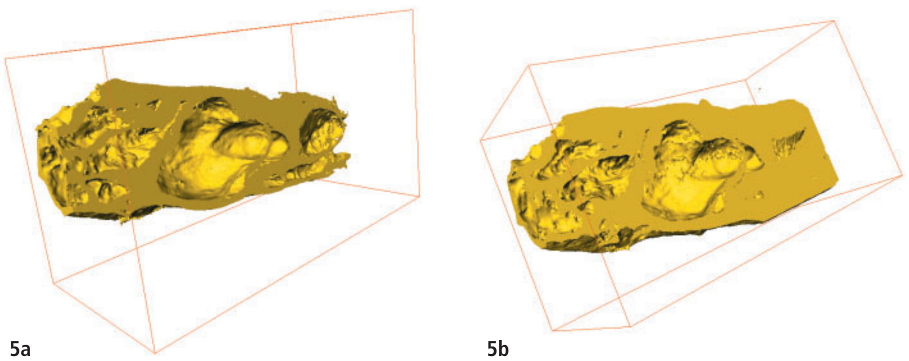

Fig. 5: 3-D reconstructions of the interior of a rice kernel before (a) and after (b) cooking for 15 s (reconstructed from 586 horizontal cross sections (box of 3.9x1.5x6.8mm´s).

Literature

A list of references can be obtained from the authors.

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