High-resolution micro- and nano-CT of soft food materials: InsideFood

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Aims

Many foods contain structural features (such as air spaces, cells, cell walls) that are manifested over a large range of dimensions, including the nanometer range[1].
To make significant advances in delivering foods with excellent quality, the role of microstructure, and its interactions with composition and external conditions must be understood and implemented throughout the supply chain. Controlling microstructure can only be achieved by accurate techniques that detect changes in the internal structure of foods.
In this study, a sugar foam and fresh apple were selected as case studies to assess the applicability of high-resolution CT on soft and moist materials.
The foam, being a reproducible model food, was used to evaluate micro-CT and the more recently available nano-CT in terms of the maximum achievable and optimal resolution to be obtained on soft samples.
Apples were chosen to address the actual problem of browning disorders during postharvest storage. The origin of this disorder is related to unfavorable gas conditions in the coolroom[2], but to date is not yet completely understood. The aim was to develop a minimally invasive method for the detailed monitoring of the changes in the microstructure of apples as affected by internal disorders.

Method

Sugar foams were produced in the lab by a standardized procedure (SGGW, Warsaw, Poland) and poured into different sized cylindrical sample containers to facilitate later sample preparation and mounting. Samples were scanned on the SkyScan 1076, 1172 and 2011 systems, in a range of pixel resolutions (35, 22, 11, 5, 3, 1, 0,7 and 0,5 µm pixel sizes).

Apples (Malus domestica Borkh., cv `Braeburn') were picked on October 27th 2010 in an orchard in Sint-Truiden (Belgium), and stored in Controlled Atmosphere (CA) coolrooms (VCBT, Heverlee, Belgium) at 1°C under 2 different gas conditions: brown-inducing (1% O2; 5% CO2) and optimal (3% O2; 0,7% CO2) conditions. Cylindrical apple samples (diameter = 6,5mm; height = 5 mm) were excised using a cork screw and wrapped in polymer foil to prevent dehydration. Samples were scanned on a SkyScan 1172 system, after regular CA storage durations (at harvest or after 1, 2, 3, 4 or 5 months of storage).

A source voltage ranging between 40 and 60 keV was applied for scanning these relatively 'soft' food materials. For high-resolution imaging, scan times typically ranged between 20 minutes and a few hours.

Reconstructed images were analyzed and visualized using CTAn (SkyScan, Kontich, Belgium) and Avizo (VSG, Bordeaux, France).

Results

A multi-scale CT approach was chosen to explore the foam's microstructure, revealing a complex structural organization. Bubbles from different size ranges were segmented at each image resolution, highly influencing porosity measurements of the samples (figure 1). As a result, an elaborate bubble size distribution graph could be constructed, with bubble diameters ranging from 1 to 1500 µm. This provided a comprehensive insight in the 3D structure of the model food (figure 2), which in the future can be linked to other sensory characteristics (e.g. properties involving light, texture) relevant at certain spatial dimensions.

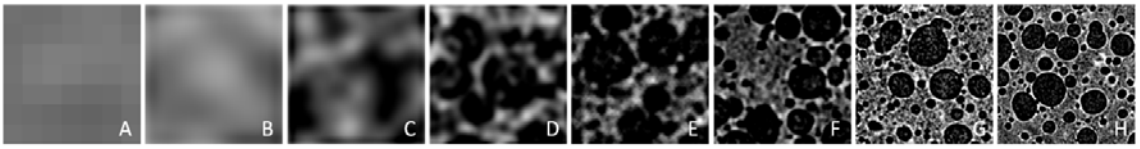

Figure 1: Selection of 2D micro-CT image (field of view = 250 x 250 µm^2) of the sugar foam scanned at pixel resolutions of 35,3 (A); 22,6 (B); 10,7 (C); 5,2 (D); 3,3 (E); 1,3 (F); 0,7 (G) and 0,5 µm (H).

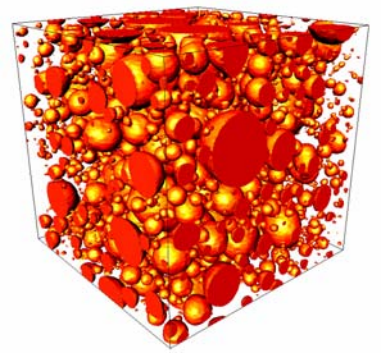

Figure 2: 3D visualization of segmented air bubbles in foam scanned at 0,5 µm pixelsize (250 x 250 x 250 µm^3).

Apple samples were scanned in a time series, to investigate the changes in the microstructure during the storage season (figure 3). Immediately after harvest, cortex tissue samples showed a porosity of 14,6%. After 1 month of storage under brown-inducing conditions, the apples manifested internal browning (macroscopically), which could be related to drastic changes of the fruit's microstructure, with cortex porosities as low as 3,1%, indicating loss of cellular integrity. Later on in the storage season, the cortex tissue degraded, resulting in the formation of holes in the tissues, with increased porosities up to 41,2%.

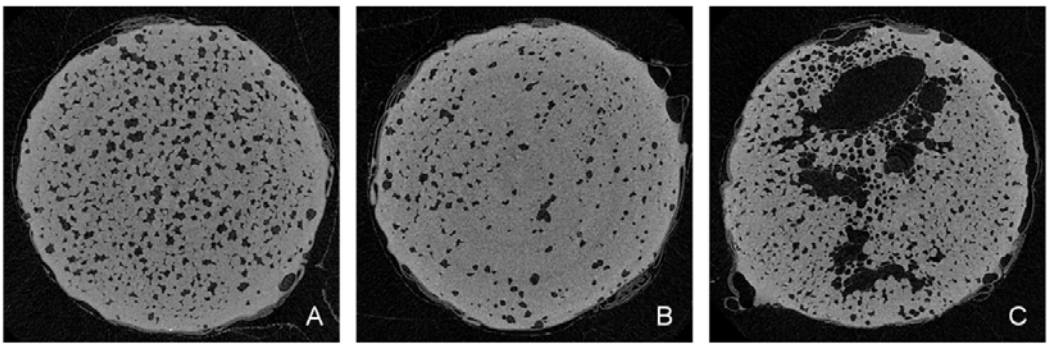

Figure 3: 2D µCT cross-sections of Braeburn apple tissue samples (field of view = 7,25 x 7,25 mm^2), stored under brown-inducing conditions during 0 (A), 1 (B) and 2 (C) months.

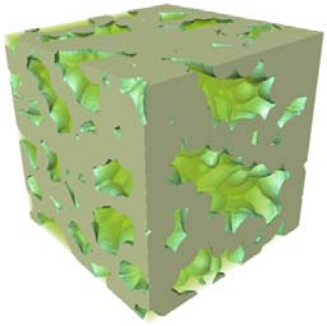

Figure 4: 3D visualization of cortex apple tissue, differentiating between cells (opaque) and intercellular void network (transparent)(1,28 x 1,28 x 1,28 mm^3).[3]

Conclusion

X-ray CT was very effective for imaging the microstructure of these selected porous products. The distinct phases of the foods (solid matrix and air spaces) could be segmented due to a high contrast in X-ray absorption, enabling extraction of 3D microstructural geometric information. Nano-CT provided complementary structural information to micro-CT, in particular regarding the pore size distribution of the model foams. X-ray Micro-CT is an exciting tool to study postharvest quality of fruits at high-resolutions. The micro-CT data presented a detailed structural insight into the fruit tissue (figure 3) and will help explain the origin as well as the development of browning during long-term storage of apples.

Acknowledgements

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References:

1. Athene Donald, "Food for thought", Nature Materials, vol.3, 579-581, 2004.
2. A.A. Saquet, J. Streif & F. Bangerth, "Reducing internal browning disorders in Braeburn apples by delayed controlled atmosphere storage and some related physiological and biochemical changes", Acta Hort, 628, 453-458, 2003.
3. Quang Tri Ho, Pieter Verboven, Bert E. Verlinden, Els Herremans, Martine Wevers, Jan Carmeliet & Bart M. Nicolaï, "A 3-D multiscale model for gas exchange in fruit", Plant Physiology, in press, 2011.