Investigation of the eye formation in semi-hard cheese by using X-ray Computed Tomography

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Abstract
The eye formation in semi-hard cheese was investigated by using X-ray Computed Tomography (XCT). In order to set the optimal scan settings, a study of parameters was undertaken. Therefore, five different scan parameter combinations and two beam hardening correction (BHC) methods were tested. An Iterative Artifact Reduction (IAR) was compared to a correction approach that is based on a collection of predefined BHC curves. VG Studio MAX and Modular Algorithms for Volume Images (MAVI) were used to determine the overall volume of the eyes, as well as the number, size, distribution and the shape factor. As a result, the cheese sample contained 749 eyes and the overall volume of the eyes was 440.84 cm³. The sphericity of the measured eyes was 0.81 with a standard deviation of 0.178. Therefore, XCT and different imaging software tools allow an exact characterization of the inner structures of cheese.

Keywords: X-ray Computed Tomography, Iterative Artifact Reduction, beam hardening, eye formation, cheese

1 Introduction
The eyes in semi-hard cheese are caused by fermentation of propionic acid. Their emergence is influenced by manufacturing as well as maturation processes and are an important sign of quality [1]. It is hence imperative to use XCT to analyze the eye structure in semi-hard cheese.

X-ray Computed Tomography (XCT) is a non-destructive imaging method, in which an object is irradiated with X-rays. The attenuation of X-rays by the material, describable by the Lambert-Beer’s law, is then detected, and a large number of radiographic projections are taken. By using mathematical algorithms, the radiographic projections are then reconstructed in order to create cross-sectional images, which can then be stacked to form a three-dimensional (3D) volume of the object [2]. Based on the information from the reconstruction, software tools for image analysis allow the determination of inner structures. Thereby information concerning the total cheese volume and the total eye volume can be obtained. Further parameters such as shape factor or size distribution of the eyes can be generated in order to obtain a better understanding of internal structures and receive relevant information about the eye formation in cheese.

2 Material and Methods
For the CT scans, a RayScan 250E equipped with a 2048 * 2048 pixel flat panel detector was used. To optimize the scan quality, a parameter study was performed. Therefore, a ready matured cheese sample with a fat content of 35% and a weight of 3 kg was scanned with different parameters, which are shown in Table 1.

Table 1: Scan parameters that were used for the parametric study

<table>
<thead>
<tr>
<th>Scan parameters</th>
<th>Unit</th>
<th>Scan 1</th>
<th>Scan 2</th>
<th>Scan 3</th>
<th>Scan 4</th>
<th>Scan 5</th>
</tr>
</thead>
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<tr>
<td>Voltage</td>
<td>kV</td>
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<td>120</td>
<td>150</td>
<td>180</td>
<td>180</td>
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<td>Current</td>
<td>μA</td>
<td>1000</td>
<td>833</td>
<td>666</td>
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<td>550</td>
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<td>Detector gain</td>
<td>pF</td>
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<td></td>
<td></td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Cu-Filter</td>
<td>mm</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>Scan time</td>
<td>min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>Voxel size</td>
<td>μm</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>155</td>
</tr>
</tbody>
</table>

2.1 Beam hardening correction
Subsequently, to correct cupping artefacts, two different linearization methods were tested for their suitability for cheese. The first method was an Iterative Artefact Reduction (IAR), that determines a correction curve from the test specimen itself with methods of image processing, whereby only one iteration has been performed [3].

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The second correction approach was based on a collection of predefined beam hardening correction (BHC) curves [4]. These curves were tested iteratively, and the resulting reconstruction was empirically evaluated. After all scans were performed, the quality measure (Q) was determined for each reconstruction. The quality measure represents a global quality criterion that is calculated on the basis of a grey value histogram. The evaluation of this method is given in an article by Reiter, et al [5].

2.1 Analysis and visualization of CT-Data

VG Studio MAX and Modular Algorithms for Volume Images (MAVI) were used to visualize and analyse the CT data regarding the number, size and shape of the in the cheese. In order to detect the eyes, the advanced surface determination was performed in combination with an ISO 70 threshold. This high ISO value was used to determine even small eyes that are affected by partial volume and blurring effects. As the local threshold method defines the material boundaries by locally adjusted grayvalues over segmentation, beam hardening and other artefacts were largely compensated. Then the inverted surface was segmented and exported in order to use the same eye structure for further analyses with MAVI. The segmented volume was imported into MAVI to perform a separation of the eyes, which were detected as one by virtue of the larger voxel size (see Figure 1).

![Comparison of two voxel sizes VS to demonstrate the loss of information caused by a larger VS of 155 μm (right) compared to a smaller VS of 70 μm (left)](image)

In MAVI a Preflooded Watershed was used to determine the correct number of eyes in the sample. Since the segmented volume at this point contains only eyes, the upper threshold was set as equal to 1. This included all existing eyes for the further binarization. To find the optimal segmentation parameters, four different thresholds were tested, and their results compared empirically. As a result, a threshold of 200 was determined to be optimal for this eyes network. The sphericity $f_1$ was then calculated by using the following equation, where $V$ represents the volume and $S$ the surface of the eye.

$$f_1 = \frac{\sqrt{V}}{\sqrt{S}}$$

3 Results and Discussion

The quality measure Q of the different scan parameters is shown in Figure 2. The graph indicates that both tested correction methods reduce beam hardening artefacts and therefore improve the scan quality. Comparing the different scans and correction methods, it is conspicuous that the IAR should be preferred. Furthermore, the scan performed with a tube voltage of 120 kV and corrected with IAR shows the highest Q-value with 14.56. This indicates that these parameters should be preferred for analyzing this type of ready matured cheese.

![Quality measure Q for the tested scan parameters and linearization methods, Iterative Artefact Reduction (IAR) and predefined beam hardening correction (BHC) curves](image)
By accumulating the information on the Q-value and the slice images, shown in Figure 3, it becomes clear that the 0.5 mm Cu filter improves the scan and reduces the beam hardening artefacts. Furthermore, there are clear deviations in the quality between the corrected and uncorrected reconstructions.

In Figure 3 (d) the histograms of the different scans are shown. Comparing the different histograms, the air peak and especially the material peak in scan 2 result in more pointed peaks compared to the material peaks of scan 4 and 5. Also, in all histograms there is a second small peak located close to the air peak. These small peaks represent the eyes in the cheese while the large peak represents the background (air that is surrounding the cheese). By comparing the three different air peaks, the IAR corrected scan shows a more homogeneous peak where the grayvalue of the background and the eyes are more similar. Therefore, the presence of this second smaller peak is a possible indicator for existing artefacts. Furthermore, the material peak of scan 4 and 5 are farther apart which could also be a marker for cupping artefacts present in the scan.

Figure 4 shows the Q-value and the slice images of the BHC corrected scans 3 and 5 compared to scan 2 corrected with the IAR. Considering these results, the use of a copper filter with a thickness of 0.5 mm in combination with BHC leads to a lower Q-value and to more clearly visible artefacts in the sliced image.

Figure 4 (d) shows the histograms of the different BHC corrected scans 3 and 5 compared to the IAR corrected scan 2. In this graph scan 2 corrected with IAR illustrates that the material peak is more pointed than the peaks shown in the other histograms. In all three shown histograms the air peak is more pointed. Further, the additional small air peaks that were already visible in Figure 3 are hardly present in the BHC corrected scans. Therefore, this correction method is improving the grayvalue histogram peak of the air. Like in Figure 3, the material peak of scan 3 and 5 are further apart than the one shown in the histogram of the IAR corrected scan.

In both figures there is a clear difference between the IAR corrected and IAR uncorrected scans. By comparing images with smaller only slight differences like slice (a) from Figure 3 and 4, it is hardly possible to establish the optimal parameters. Accordingly, the determination of the quality measure represents an effective method to compare scan qualities also with minor differences.
With the optimized process parameters, the correct number, size and shape of the eyes were analyzed. According to this method, the analyzed cheese sample contained 749 eyes. The volume distribution of the eyes and a visualization of the inner structure is given in figure 5. This shows that the cheese mostly contains eyes < 29 cm$^3$. These eyes are highly distributed in the centre of the cheese while eyes < 6 cm$^3$ are mostly found in the outer area.

Figure 5: Visualization of the eye structure of cheese (a) and the volume distribution of the eyes (b)
The overall volume of the eyes was 440.84 cm$^3$ while the volume of the cheese material was 2676.56 cm$^3$. The sphericity of the measured eyes was 0.81 with a standard deviation of 0.178. These results show that the use of XCT and different imaging software tools allow an exact characterization of the inner structures of cheese samples.

4 Conclusion
The presented work shows that by using XCT and appropriate imaging software tools, a detailed characterization of the eye structure of semi-hard cheese is possible. By combining VG Studio MAX and Modular Algorithms for Volume Images (MAVI), the overall volume of the eyes, the number, size and distribution as well as the form factor of the eyes were determined. In order to improve the scan quality, the IAR corrected reconstructions showed the highest Q value and may therefore be preferred in order to correct for beam hardening artefacts. Nevertheless, also the BHC with predefined curves represent a fast and useful method to improve the scan quality without optimizing each scan individually with a specially generated curve.

The quality measure (Q) that was determined for each reconstruction, represents an excellent tool for comparing different scan qualities especially by comparison of images with smaller differences. This method made it possible to establish the optimal scan parameters of this type of semi-hard cheese. Not only detailed information determines the number, size, distribution and shape of the eyes was generated but also information about the spatial distribution was obtained. This enables a more precise insight into the eye distribution where small eyes tending to be located in the outer area of the cheese, while larger eyes are highly distributed in the centre. This exact characterization of the inner structures makes further detailed investigation of the eye formation in this type of semi-hard cheese possible.

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