Contactless Evaluation of Air-bubble Structure in Bread by Laser Scattering Imaging

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Abstract
An imaging apparatus consisted of a laser diode module, camera lens and monochrome CMOS camera was used to measure diffuse reflectance on the surface of 40 bread slices. Intensity profile along with the distance from the incident laser beam was calculated for each sample. The same surface of the sample was scanned using an image scanner to measure parameters characterizing air-bubble structure, that is, average area, average equivalent diameter, average perimeter, ratio of air-bubbles to total area and total number of air-bubbles. Partial Least Squares Regression models were developed to relate distance-intensity profile to these parameters. Among all parameters, average equivalent diameter could be most accurately predicted with the coefficient of determination of 0.920. Laser scattering imaging would be considered as a potential contactless method for the estimation of air-bubble structure in bread.

Key words: bread, non-destructive, physical properties, image analysis, chemometrics

1. Introduction
Air-bubble structure in bread is an important factor which affects its texture. Thus trained specialists examine bread air-bubble structure by their naked eye for quality control purpose in bread making factories. Automation of this process is needed since human inspection is labor consuming and subjective. It has been reported that an image scanner could be used as objective measurement method of air-bubble structure in bread (Shibata et al., 2010). However, this method needs the sample to be in contact with the scanner surface and thus cannot be used for quality inspection in bread making process.

Laser-scattering imaging is a method to measure the light diffuse reflection from the sample surface induced by a laser beam. Diffuse reflection is the result of light scattering and is directly proportional to the scattering properties of the material (Tu et al., 2000). Physical properties such as apple firmness (Tu et al., 2000, Qing et al., 2007) could be non-destructively measured by laser-scattering imaging. In the case of bread, air-bubbles can be considered as light scatterer whose size affects the property of diffuse reflection. The objective of this study was to investigate the potential of laser-scattering imaging as a contactless method for the estimation of air-bubble structure in bread.

2. Materials and Methods
2.1. Sample Preparation
Twenty loaves of plain bread (Double-soft, Chojuku, Hon-jikomi and English bread brands) were purchased from a local supermarket in Ibaraki, Japan. They were all cut into 4 slices of the same thickness. Total 40 slices, two from each loaf, were examined as sample.
2.2. Imaging Apparatus

The imaging system used in this study is shown in Fig. 1. The system consisted of a 633 nm laser diode module (NT54-179, Edmund Optics Japan, Inc., Japan), a C-mount camera lens (NT56-537, Edmund Optics Japan, Inc., Japan) and a monochrome CMOS camera (ORCA-Flash 2.8, Hamamatsu Photonics K.K., Japan). The working distance between the sample and the lens was set to 700 mm, while the laser diode module was placed at 450 mm distance from the sample and emitted red laser beam with 1 mm diameter or less onto the sample surface. The position of the camera and laser diode module was adjusted so that the spot illumination by the laser beam located in the center of the field of view (FOV) of the camera.

2.3. Image Acquisition

The data acquisition and analysis procedure in this study is shown in Fig. 2. A sample was placed under the camera with its center illuminated by the laser beam. Images of the sample surface were acquired at 8 different exposure times equally distributed in a logarithmic scale; 1.014, 3.117, 10.006, 31.636, 100.006, 316.228, 1000.006, 3162.288 ms. These 8 images were merged into one high-dynamic range (HDR) image in which pixel intensities were ranged in 6 orders of magnitude.

2.4. Acquisition of Diffuse Reflection Property

The center of the spot illumination was specified as the pixel with the highest intensity value in the HDR image. Then the distance from the center to each pixel was calculated. Intensities of pixels with the same distance were averaged to acquire diffuse reflection property as a distance-intensity profile.

2.5. Air-Bubble Structure Measurement

After the HDR image acquisition, the same sample surface was scanned by an image scanner (ES-H300, Seiko Epson Corp., Japan) with the resolution of 300 dpi. Then parameters characterizing air-bubble structure, average area, average equivalent diameter, average perimeter, ratio of air-bubbles to total area and total number of air-bubbles, were calculated by applying the image analysis method reported by Shibata et al.
2.6. Partial Least Squares Regression (PLSR)

Acquired data were randomly divided into calibration and validation set. PLSR was applied to the calibration data set to develop models by which relate the distance-intensity profile to the parameters of air-bubble structure. The models were then applied to the validation data set to evaluate their validity by calculating coefficient of determination of prediction (R^2_p).

2.7. Software

System development software (LabVIEW 2011, National Instruments Corp., USA) was used to control the camera. Development of HDR images, image analysis for parameters characterizing air-bubble structure and PLSR were carried out using MATLAB R2011b (The MathWorks, Inc., USA) and PLS_Toolbox 6 (Eigenvector research, Inc., USA).
3. Results and Discussions

3.1 Distance-Intensity Profile

Distance-intensity profiles of the calibration data set are shown in Fig. 3. Pixel intensities decreased exponentially along with the distance from the spot illumination. Pixel intensities were unstable in the distance range over 20 mm because the diffuse reflectance was too weak and could not be distinguished from the dark noise of the camera. Therefore, only the data in the 20 mm or less were used for the following data analysis.

3.2. PLSR Models

$R^2_p$ values of PLSR models for each parameter of air-bubble structure are shown in Table 1. Among all parameters, average equivalent diameter could be most accurately predicted. This could be explained by the fact that transport scattering coefficient, which describes which portion of the incident light is scattered, is the function of the density and diameter of the scatterers (Cubeddu et al., 2001). Difference in the diameter of air-bubble is considered to affect the transport scattering coefficient, which would be reflected in the difference in distance-intensity profile.

Fig. 4 shows the scatter plot of measured and predicted average equivalent diameter. Measured and predicted values of the calibration data set were in good agreement ($R^2=0.920$), which indicated laser-scattering imaging as a contactless method for the estimation of air-bubble structure in bread. The accuracy for the validation data set, however, showed significantly lower than that of the calibration. This could be caused by the disagreement between the theory and modelling method; i.e. while transport scattering coefficient is considered to be non-linearly related to the scatterer size, PLSR supposes linear relationship between explanatory and response variables. Further studies, including the development of a model in agreement with the light scattering theory, would be needed for the practical use of laser-light scattering imaging on bread evaluation.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$R^2_p$</th>
</tr>
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<tbody>
<tr>
<td>Average area</td>
<td>0.013</td>
</tr>
<tr>
<td>Average equivalent diameter</td>
<td>0.5287</td>
</tr>
<tr>
<td>Average perimeter</td>
<td>0.0182</td>
</tr>
<tr>
<td>Ratio of air-bubbles</td>
<td>0.4009</td>
</tr>
<tr>
<td>Number of air-bubbles</td>
<td>0.0086</td>
</tr>
</tbody>
</table>

TABLE1: $R^2_p$ Values for PLSR Models
4. Conclusions

Distance-intensity profiles, which reflected diffuse reflection of the sample, were related to air-bubble parameters by applying PLSR. Average equivalent diameter of the calibration data set could be accurately predicted, showing the potential of laser-scattering imaging as a potential contactless method for bread evaluation. The prediction accuracy for validation data set, however, was significantly lower than that for the calibration, which indicated the need for further studies.

Reference List


