

Application of X-ray computed tomography using synchrotron radiation to frozen food

Freezing is an essential method of preserving food for storage and logistics in food manufacturing. Control of the size, shape, and distribution of ice grains in frozen food is important for reducing damage to food. We investigated the capability of X-ray computed tomography (CT) as a nondestructive observation technique for the internal structures of frozen foods using SPring-8. It is difficult for a laboratory X-ray CT apparatus using white X-rays to distinguish ice grains from other substances in frozen food, because the difference in density between ice and other substances is not significant for white X-rays. Utilizing synchrotron radiation (SR) as the light source enables us to use a highly brilliant and monochromatic X-ray beam. Monochromatic X-rays improve the contrast of CT images, making the ice grains in frozen food distinguishable.

We developed a specimen freezer for keeping food specimens frozen on an X-ray CT apparatus as shown in Fig. 1. This equipment keeps the temperature of specimens at about -30°C by blowing liquid nitrogen (LN_2) vapor. The noncontact freezer does not disturb turning the specimen and accepts various shapes of specimen, whose horizontal thickness must be less than *ca.* 6 mm. Examples of CT images of frozen food are shown in Fig. 2; these are the

tomograms of frozen tuna (Fig. 2(a): horizontal, Fig. 2(b): vertical) [1]. The measurement was carried out at SPring-8 BL19B2. The energy of the X-rays was 12.4 keV. The specimen was irradiated with the X-ray while turned at a speed of 1.2°s^{-1} . A set of 256 transmission images was acquired during turning the specimen throughout 0-180 degrees. The exposure time for each image acquisition was 120 ms. The X-ray camera used for the image acquisition was an X-ray imaging system composed of an AA40 X-ray imaging unit and a C4880-41S CCD camera manufactured by Hamamatsu Photonics K.K. The distance from the specimen to the X-ray camera was set at 100 mm. The size of the pixels in the image data was $2.9 \times 2.9 \mu\text{m}^2$. These images indicate the linear X-ray absorption coefficient μ of the matter in the specimens with a gray scale, in which a dark area means a large value. Ice grains are clearly indicated as light gray areas, where the mean μ value of 2.59 cm^{-1} is consistent with that of ice. Because the specimen was frozen by slow cooling, ice grains were coarsened and the other substances shrank into the dark gray bands elongated vertically along the direction of the muscle fibers. The utilization of highly brilliant and monochromatic X-rays made it possible not only to improve the contrast of CT images but

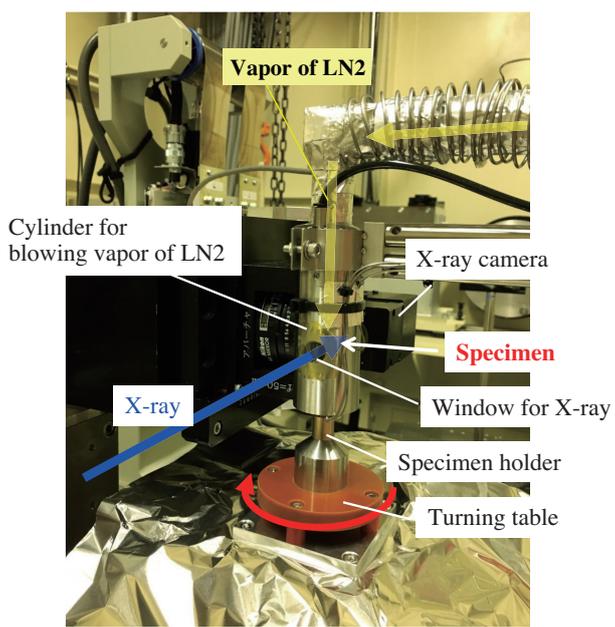


Fig. 1. View of the specimen freezer for the X-ray CT of frozen food.

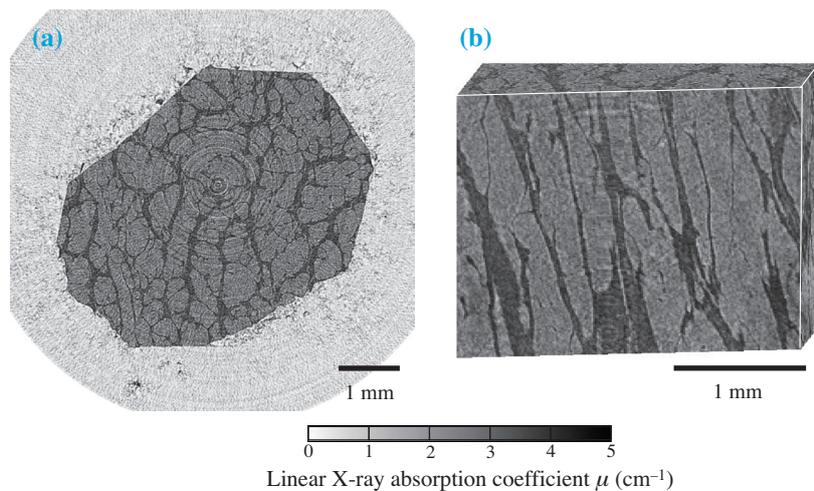


Fig. 2. Tomograms of frozen tuna. (a) Horizontal cross section. (b) Vertical cross section.

also to analyze the constituent distribution in the frozen food quantitatively. Figure 3 shows frequency distributions of the μ value at each pixel in tomograms of frozen tuna and raw tuna. The profile of data for raw tuna can be fitted to a single peak described with a Gaussian function as shown by the yellow line. The single peak reflected the fact that the substance in the raw tuna was homogeneous. On the other hand, the profiles of data for frozen tuna consisted of two peaks, as shown by the light blue line, whose profile was reproduced by the sum of the two Gaussian functions indicated by thick and dotted blue lines in the figure.

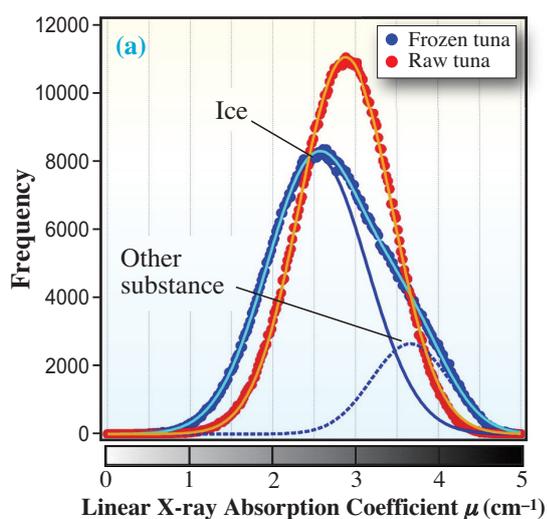


Fig. 3. Frequency distributions of value of μ of each pixel in the tomograms of frozen tuna (red circles) and raw tuna (blue circles).

The thick-line peak indicates ice grains and the dotted-line peak indicates the other substances. Comparison of the peak for the substances other than ice in frozen tuna with the peak for raw tuna shows that the center of the former peak is shifted to a larger value of μ from that of the latter peak. This means that the increase in the densities of the substances other than ice in frozen tuna was caused by freezing. The increased density suggests that the utilization of highly brilliant and monochromatic X-rays from SR in X-ray CT enables not only the morphological observation of ice grains but also quantitative analysis of the condensation of materials in frozen food.

This technique has been applied to various frozen foods, for example, frozen fruits [2], and frozen pasta [3]. The capability described here is currently available to users at BL14B2 and BL46XU.

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References

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