[課程博士・論文博士共通]

博士学位論文内容要旨
Abstract of Dissertation

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論文題目 Title	Study on physical properties of food inks and their application in stereolithography 3D food printing		

The water uptake behavior of food powders and the gelatinization behavior of starch by localized heating using laser irradiation were elucidated through magnetic imaging resonance (MRI) and numerical simulation analysis in order to realize the industrial application of stereolithography 3D food printing. The stereolithography printing is a technology to create 3D food products by mixing vegetable and livestock powders and starches with water to prepare food ink, and then to heat the surface with laser irradiation to solidify the food inks through starch gelatinization. Then, this process is repeated to stack the solidified food ink layer by layer to make 3D printed foods. This technology enables localized heating of food inks with micron-order precision by laser irradiation, allowing for the manufacturing of 3D food products with complex shapes with formativeness, which is more advantageous over conventional extrusion 3D food printing. However, at the present time, there are several challenges hindering the industrial application of this technology. For instance, the preparation of food inks is difficult due to the low water uptake of powders made from food ingredients. Additionally, the gelatinization behavior of starch in food inks, which is intrinsically related to the formativeness of 3D printed food as well as its texture and sensory properties, remains unclear and needs to be clarified. Therefore, the aim of this study is to elucidate the water uptake behavior of food powders and the gelatinization behavior of starch by localized heating using laser irradiation from the perspective of food physical properties to realize the industrial application of stereolithography 3D food printing. Summaries of the results of these studies are described below:

1. The water uptake of potato and soybean powders was investigated by capillary action and magnetic resonance imaging (MRI) experiments. The potato powder exhibited higher water uptake than the soybean powder, a result which was attributed to the different powder compositions. Potato and soybean powders exhibited different wetting, swelling and dispersion behaviors in water. MRI experiments also demonstrated the difference in water uptake between the powders, and indicated the formation of air bubbles, which could hinder water uptake. Numerical simulations based on a gravity-corrected Washburn-model were further performed to elucidate the mechanism of water uptake. The simulations and experiments were in good agreement. We demonstrated that powder swelling, and a dissolution-driven viscosity increases opposed water uptake and produced an eventual plateau. Our results suggest that the model used in our simulation can explain the effects of powder swelling and viscosity changes on water uptake.

2. The laser heating in 3D food printings can give a formativeness to food inks by the laser-controlled gelatinization of the paste which improves the handling of the food ink materials. The gelatinization behavior of wheat starch paste by a laser heating have been elucidated. The localized heating by laser irradiation caused the gelatinization of the paste in a millimeter order width which caused a subsequent water migration from the ungelatinized region by the water demand associated with the gelatinization. Polarized microscopy, scanning electron microscope (SEM) observation and magnetic resonance imaging (MRI) have been carried out for the elucidation. The cross-section observation by a polarized microscope showed the melting of starch granule crystals in the laser heated region, and SEM observation indicated the collapse of starch granules to give the gelatinized lumps engulfing the water. MRI measurements gave the distribution of water content in the laser

heated paste suggesting the water migration from the ungelatinized region where the gelatinization by the following laser heating was restrained because of the low water content. The water migration was reproduced in a model paste sheet with one side heating where the side was gelatinized with the increase of water content and another side decreased in the water content. The results of this study provide useful information on developing laser cooking techniques, allowing laser heating to find potential applications in the food processing industry including 3D food printing.

Conclusively, these results provide useful information on developing the technology for improving the water uptake of food powders for food inks and laser cooking techniques, enabling potential applications in the food processing industry including 3D food printing.