Development of quality evaluation methods and simulation models for large scale cooking

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In food service facilities such as schools and hospitals, it is required to always provide food of consistent quality. For root vegetable stews and soups, which are frequently served, it is important to control quality such as texture and shape collapse, and it is thought that temperature changes in the pot and the weight of the ingredients are concerned. However, there are no reports that have experimentally verified the effects of various factors and proposed quality control methods. The purpose of this study was to develop a quality evaluation method and a model to predict the state of cooked product in order to propose a quality control method for large scale cooking of root vegetables.

First, the changes in internal temperature and hardness of root vegetables were simulated based on the slow water temperature change in cooking using a tilting kettle, and the cooking time was predicted. When a large amount of food is put into boiling water, it has been considered necessary to pay attention to the decline in water temperature. However, under the condition where 12 kg of 2 cm cube Japanese radish was put into 8 kg of boiling water, the boiling time was shorter than that of 99.5°C constant heating due to the softening process before re-boiling. It is also said that in large scale cooking, the residual heat after stop heating is large enough to cause shape collapse of root vegetables. Therefore, the optimum residual heating time was set to achieve an optimum hardness for a sample of 1/12 potato sample in 10-50 kg of water, which was almost the same duration as the boiling time without using residual heat. Then 12 kg of potatoes and 8 kg of water were cooked, and it was confirmed that at the optimum residual heat usage time, the amount of cooking loss was reduced by 1/3 compared to the case where the water temperature was left to reach 70°C for a long time. Since the intense convection of bubbles generated during boiling during heating is also considered to be a factor of shape collapse of potatoes, the next step was to understand the relationship between the generation of bubbles and the extent of shape collapse of potatoes. The maximum bubble length diameter when only water was heated was used as an indicator of the degree of bubble generation, and the heated samples were evaluated on a six-step scale focusing on surface changes. The larger the gas flow rate, the larger the maximum bubble length diameter, and the more shape collapse of potato samples progressed. Therefore, it can be said that in order to prevent potatoes from shape collapse in large scale cooking, it is effective to take them out at the optimum residual heating time without continuing boiling.

Another factor that can cause shape collapse of root vegetables is the stacking of a large amount of food. There have been reports on damage to fresh fruit during stacking, but no reports on cooked food. In this study, we first examined the differences in the samples and the conditions under which they were left in a tilting kettle, using a stacking model experiment that reproduced the center of the kettle when cooking a total weight of 30 kg. Potato and Japanese radish samples weighing about 1.2 kg were stacked in 5 layers in a metal basket, heated in 30 kg boiling water, and left in water or air for 2 hours. After leaving, samples were evaluated their weight and shape collapse. For potatoes, the difference in position in the basket was small under all conditions, so the effect of stacking was small. The deformation of Japanese radish was also small when left in water. On the other hand, when left in air, the lower part of the Japanese radish samples deformed and its weight decreased due to water release. Next, a constant load compression test was performed to simulate the stacking condition, and the change in strain of a 2 cm cube of Japanese radish was analyzed using a six-element creep model. The semi-log plot of the apparent viscoelastic moduli versus heating time showed a linear decrease except for E_H, so the apparent viscoelastic moduli could be calculated for any heating time and the strain could be predicted. The percentage reduction of weight could also be predicted based on the linear relationship with the strain. Lastly, 8 kg of cooked Japanese radish samples of fan shape were left in a food container for 2 hours, and then the weight, height, and radius were measured and evaluated their shape collapse. As a result, it was confirmed that the deformation was larger at the lower part of the container, the weight decreased, and the height became the same level as the constant load compression test. The weight was about 0.8-0.9 times higher than that of the constant load compression test because the samples were subjected to forces from various directions in the food container, resulting in a smaller radius and complex shape collapse.

Finally, we verified that uneven heating is said to occur easily in large scale cooking. First, the water temperature change during heating was measured in 5 and 28 L stock pot and a tilting kettle with 55 L of water at the brim, with the total weight of the sample and water at 3 kg and 20 kg respectively, and the percentage of sample weight at 0, 25, and 60%. Nylon cylinders with diameters and heights of 1, 2, and 3 cm were used as samples. The rate of water temperature increase from the start of heating to 99°C increased linearly with the percentage of sample weight, and when the total weight was 3 kg and the percentage of sample weight was 60%, the rate of water temperature increase increased with the size of the sample. The water temperature distribution and flow in the pot were then visualized by CFD (Computational Fluid Dynamics) analysis using COMSOL Multiphysics®, a finite element based simulation software. By using the measured water temperature near the inner surface of the pot as a boundary condition, the water temperature in the pot could be predicted regardless of the total weight or the presence of the sample. The Rayleigh number, which indicates the onset and strength of convection, was 46.7 times and 3.3 times higher for 20 kg than for 3 kg at 0% and 60% sample occupation area ratio, respectively, indicating that convection was more likely to occur when the total weight was larger. On the other hand, the larger the sample occupation area ratio, the smaller the sample, the lower the velocity at a total weight of 3 kg. Although convection was disturbed by samples, it was suggested that the water temperature rose faster in the larger sample because the flow channel was wider and convection occurred more easily. It was possible to show the difference in water temperature and flow in the pot due to these various cooking conditions.

The optimum residual heating time for root vegetables, the evaluation and prediction method for deformation of root vegetables, and the prediction model for water temperature and flow in the pot during cooking proposed in this study will contribute to the quality control of large scale cooking, which has been done empirically.