外国語要旨

学位論文題目　Study on Evaluation Method for Staling of Cooked Rice

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Staling of cooked rice is a phenomenon in which the appearance, hardness, and stickiness change after cooking during storage, especially under refrigerated storage, and the palatability deteriorates. The retrogradation of starch, which is the main cause of staling of cooked rice, is a phenomenon in which amylose and amylopectin molecules partially associate into an aggregation and undergo recrystallization. Retrogradation of starch is investigated based on the degree of gelatinization by an enzymatic method, evaluation of thermal characteristics by differential scanning calorimeter, and X-ray diffraction, however it does not necessarily agree with phenomena such as physical property changes caused by staling of cooked rice. Therefore, in the evaluation of staling of cooked rice, it is necessary to clarify the relationship between the sensory score (degree of staling of cooked rice) by panelist and objective measured values such as physical properties and retrogradation of starch. However, from this point of view, there have been few investigations on multiple evaluations of staling of cooked rice. This study aimed to construct a new evaluation method of staling of cooked rice by multiple evaluations such as sensory evaluation, physical property, retrogradation of starch, and image analysis of cooked rice grain.

First, five rice varieties with different amylose content were cooked with different amount of cooking water and the cooked rice were used for experience. Sensory evaluation was conducted on "degree of staling" of cooked rice stored at 4°C for 0–48 hours. Furthermore, the relations between the sensory score (degree of staling) of cooked rice and the objective measurement value such as retrogradation of starch and measurement of physical properties were examined by Pearson's correlation coefficient and multiple regression analysis. As a result, "degree of staling" of cooked rice by sensory evaluation was predicted by a multiple regression equation, with the hardness and stickiness values measured by Texturometer : $y = 0.86\,x_1 - 3.15\,x_2 - 0.48$ (y, the degree of staling of cooked rice by sensory evaluation; x_1, hardness value by Texturometer; and x_2, stickiness value by Texturometer; $R^2 = 0.87$).

Subsequently, staling of cooked rice was evaluated by the rate of changes in the hardness and stickiness of the cooked rice measured by Texturometer. Five polished rice varieties with different amylose contents were cooked, sealed, and stored at 4°C for 168 h. As changes in the values of hardness and stickiness of cooked rice tended to become less pronounced with increasing storage time, the first-order rate law was used for analyzing the hardness increase and stickiness decrease of cooked rice over time during storage. The hardness and stickiness values were replaced by dimensionless values as the ratio of hardness increase and as the ratio of stickiness decrease for analysis. The slope of first-order plots of hardness and stickiness changed during storage; the change process was divided into two periods: the first and latter halves of the period, each with different rate constants. The rate

constant of hardness increase in the first half period was greater for rice with a higher amylose content; conversely, in the latter half period, it was greater for rice with a lower amylose content. From the values of the rate constants, the hardness increase of cooked rice of five varieties could be classified into the following three types: type 1, hardening early with a larger rate constant in the first-half period; type 2, hardening at a rate that is similar to that in the first-half and latter-half periods; and type 3, late-start hardening with a higher rate constant in the latter-half period. The three types of rate constant suggested the characteristics of hardness increase of rice varieties. The rate constant for stickiness decrease in the latter half was greater than that in the first half, and higher the amylose content, larger the rate constant in both periods. The simulating changes in quality of cooked rice were demonstrated using the stickiness–hardness ratio and the staling score which were calculated from rate constants and other parameters obtained by kinetic analysis.

Next, a new evaluation method of staling of cooked rice was examined. When cooked rice becomes staler, the squashed cooked rice grain becomes whiter and powdery. The cooked rice grains after storage at 4°C were squashed to 0.1 mm thickness, and color measurement and image analysis of the squashed cooked rice grains were performed to evaluate the difference in staling level of five varieties of cooked rice. As a result, during storage at 4°C, the shape of the luminance histogram of the image of squashed cooked rice grain by the transmitted light changed from a sharp right-rising peak (indicating high ratio of high luminance area) to the flat or left-rising peak (indicating increase in the ratio of low luminance area). Such visual changes shown as luminance histogram in the squashed cooked rice grains were consistent with the tendency of changes in physical properties and staling score by sensory evaluation, which suggested the change in the level of staling of cooked rice. In addition, the image of squashed cooked rice grain was binarized (threshold value: the gray level 130) to obtain Ratio of White Area$_{\alpha 130}$, which showed the area of gray level to be ≤130. The correlation coefficients among Ratio of White Area$_{\alpha 130}$, the color (L *) of the squashed cooked rice grain, physical properties, and staling score by sensory evaluation were $|0.78| - |0.96|$, indicating a high correlation. Apparently, it was evident that the method of evaluating the staling of cooked rice based on the color measurement and image analysis of squashed cooked rice grain was a useful and new evaluation method that can visually and quantitatively demonstrate the staling of cooked rice.

In addition, retrogradation of starch in cooked rice stored at 4°C was measured by DSC and X-ray diffraction. Relationship among the retrogradation level of starch in cooked rice, staling score by sensory evaluation, and physical properties value was examined. Recrystallization of starch by X-ray diffraction was observed only in cooked rice with the extreme deterioration of palatability, because of changes in physical properties. This result suggested that it was difficult to capture staling of cooked rice at an early stage by X-ray diffraction. In DSC, the correlation coefficients between measured values of hardness and stickiness and ΔH was not high, and the correlation coefficient between staling score by sensory evaluation and ΔH was not high. Therefore, measurements by X-ray diffraction and DSC on retrogradation of starch in cooked rice could roughly indicate the changes by staling of cooked rice; however, these measurements were not satisfactory as an indicator of the staling of cooked rice at an early stage.

Finally, the evaluation methods for staling of cooked rice in this study were applied to seasoning-added cooked rice, and the staling was evaluated. As a result, the rate constants of hardness increase and stickiness decrease by kinetic analysis, and the color (L*), the luminance histogram and Ratio of White $Area_{\alpha 130}$ by analyzing the squashed cooked rice grain indicated the effect of the vinegar for delaying the staling of cooked rice .

The three evaluation methods in this study are as follows: 1. An evaluation method based on the predicted value of "staling score of cooked rice" by the multiple regression equations using the values of hardness and stickiness; 2. An evaluation method of staling based on rate constant applying kinetic analysis for assessing the changes in physical properties of cooked rice; and 3. An evaluation method that can visually and quantitatively show the staling of cooked rice by analyzing the color and image analysis of squashed cooked rice grain. The three evaluation methods for staling of cooked rice can greatly contribute to the quality evaluation and the quality control of cooked rice.