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REVIEW

Application of Instrument-Based Multiple Texture Measurement of Cooked Milled-Rice Grains to Rice Quality Evaluation

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Abstract

The subject of this study was to examine a method of multiple texture measurement of cooked milled-rice grains and to develop techniques for quality evaluation on the basis of the method. The low-and high-compression (LHC) test, which measures surface and overall texture properties (25% and 90% compression ratios for the single grain thickness after cooking), was effective in enhancing the classification accuracy of the texture. A multiple regression model based on surface texture properties indicated higher prediction accuracy for palatability than that with using overall texture properties. The surface adhesion distance was adopted for distinguishing stickiness. Concerning the effect of protein content on texture among the samples of the same cultivar given different amounts of nitrogen fertilizer, the protein content showed a higher correlation with surface hardness than with overall hardness. Surface hardness was a more reliable indicator of protein content and palatability in the same cultivar. It revealed that the surface texture can be used as a key quality index. A multiple regression model of the LHC test was able to predict amylose content more precisely than using the conventional method. It was possible, using the single-grain method with the LHC test, to evaluate not only grain texture but also many other qualities such as protein content, palatability and amylose content.

Discipline: Food
Additional key words: amylose, palatability, protein, quality

Introduction

According to statistics data obtained in 2001 by the Ministry of Agriculture, Forestry and Fisheries of Japan (MAFF), current annual rice production in Japan amounts to approximately 3,000 billion yen, which accounts for about 30% of the total agricultural production, making rice one of the most important crops in domestic agriculture. Rice is a staple food for the Japanese but its consumption is decreasing year by year. To reverse this trend, it is necessary to provide rice cultivars which can satisfy the requirements of both the food industry and of consumers with respect to rice quality. It is thus essential to develop quality evaluation methods to enable these requirements to be met. Palatability of rice, which is becoming increasingly important, is comprehensively determined by aroma, appearance, taste, and texture. Cooked rice texture, such as hardness and stickiness, is an important factor in its palatability. Many studies have been performed on rice grain texture[3,5,9,10,17,21]. However, the best eating quality rice cultivars such as ‘Koshihikari’ or its relative cultivars have been recently becoming dominant in Japan, and these cultivars have similar texture. On the other hand, several non-waxy cultivars with extremely low or high amylose content, and low glutelin content offer different characteristics from conventional cultivars, and their growing area is increasing slowly. It is therefore essential to develop high-sensitivity methods to clearly enable differentiation of the texture and the quality not only among similar cultivars, but also among rice cultivars that vary widely as to quality. The subject of this study is to develop an advanced rice quality evaluation method by a single apparatus on the basis of texture measurements of cooked milled-rice grains. Currently, texture properties of cooked rice grains are quantified by carrying out several different physical tests. We attempted in this

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study to select a suitable texture attribute or chemometric model for evaluating texture, the palatability or the chemical components.

Multiple-texture measurements of cooked milled-rice grains

Okabe[10] developed an instrument-based three-grain method for measuring cooked rice texture, using a Texturometer. This method, which evaluates the hardness and stickiness of three cooked rice grains by large deformation, is often used in Japan. Numerous other methods have been developed to examine grain texture, using various instruments. The subject of this study, however, is to develop a sensitive single-grain method for measuring texture of a single grain after cooking. We carried out several kinds of tests with a Tensipresser apparatus (type: Myboy System, Taketomo Electric Co., Japan) and suitable tests were selected for the multiple texture measurements. Results showed that the combination of a low-compression (LC) test and high-compression (HC) test was suitable for enhancing the texture discrimination. The HC test detects the overall texture of the cooked rice grain and is close to the three-grain method at the point of the large deformation. It has the feature of determining surface texture using the small deformation employed in the LC test. In the LC test, it was proved that the compression ratio of 25% was more appropriate for differentiating the surface texture than that of 15%[11]. The two tests had to be performed separately at the beginning when developed, and it was somewhat time-consuming. In the latest procedure, improvement of the apparatus has made it possible to perform the two tests consecutively (Fig. 1). In the low- and high-compression test (LHC test) using a Tensipresser, the grain thickness was detected automatically. The grain was then first slightly compressed to 25% of its thickness and subsequently to 90%. The result was that more texture properties could be rapidly quantified. The attributes from the recorded force-time curve were analyzed on the basis of the texture profile analysis (TPA) method[2,19], using the attachment program. The texture mean values for each sample were usually calculated by measuring 20 grains but more than 50 grains were measured in some cases. As for sample preparation, brown rice samples were milled to the yield of 90 to 91%, using a friction-type rice miller. The milled rice samples (10 g) were added with 16 g of water in an aluminum cup. After soaking for 1 h, the samples were cooked in an electric rice cooker. To prevent moisture loss after cooking, the cooked rice samples were placed into glass cases and the cases were additionally covered with polyethylene film. The cooked rice samples, held for about 2 h at room temperature (approximately 25ºC), were subjected to the texture measurements.

Comparison of texture properties, using low-compression test and high-compression test

Fig. 2 shows the texture properties of the surface and overall grain of individual cooked milled-rice grains

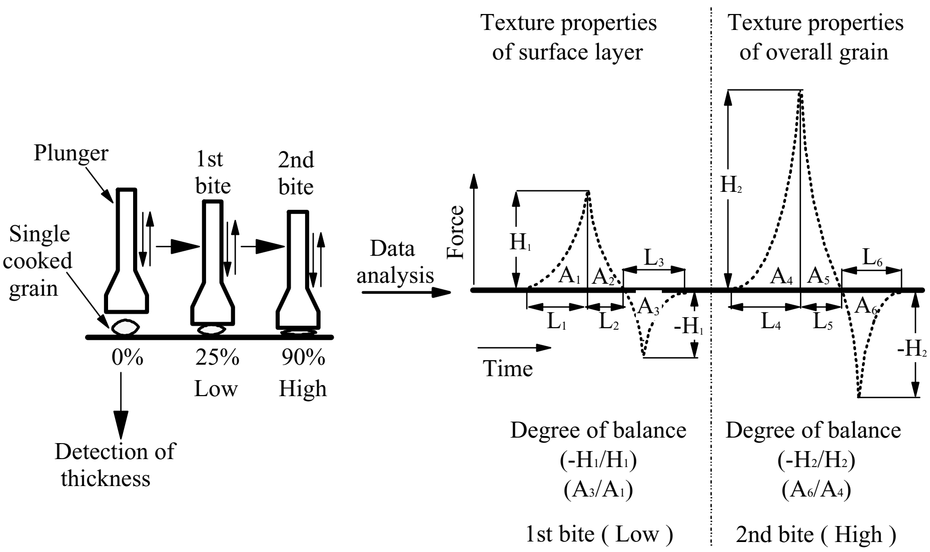

Fig. 1. Low- and high-compression (LHC) test with single cooked milled-rice grain (single-grain method)

Compression ratios for grain thickness: 25% and 90%.

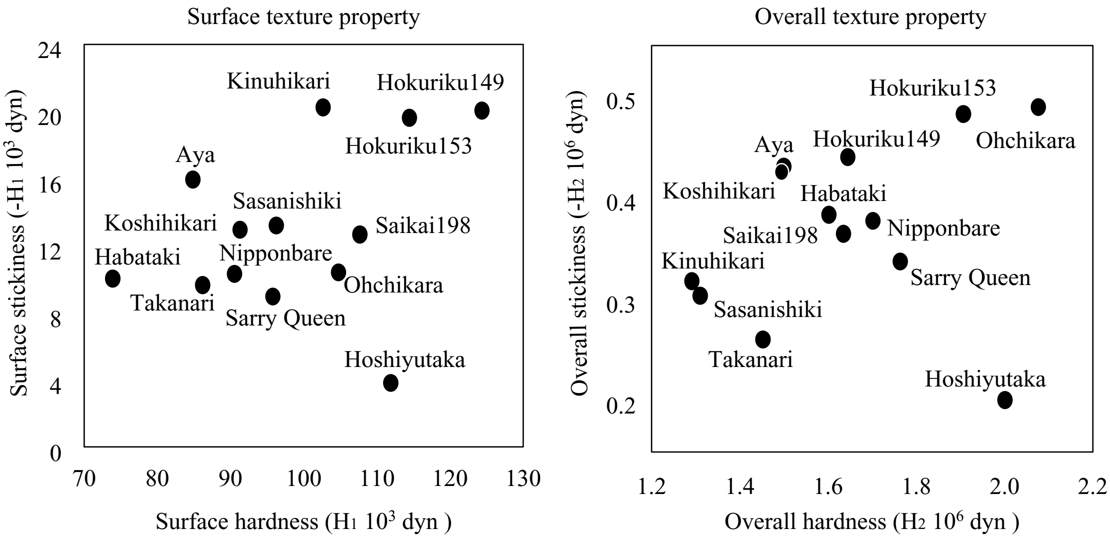

Fig. 2. Comparison of texture property of cooked milled-rice grains by low-compression (LC) test and high-compression (HC) test

Table 1. Prediction model for "overall evaluation" of sensory evaluation by low-compression test and high-compression test

Physical property test	Multiple regression models	Calibration R	Prediction R
Low-compression test	$Y = 1.07 \times 10^{-4} (-H_1) + 1.53 (L_3) - 2.19$ (0.46) (0.74)	0.92	0.67
High-compression test	$Y = 2.40 \times 10^{-6} (A_6) + 5.42 (-H_2/H_2) - 4.37$ (0.69) (0.31)	0.83	0.53

Numeric values in parentheses indicate the standard partial regression coefficient.

by the LC and HC tests. For example, 'Koshihikari', which has low amylose content, indicated the same texture as 'Aya', which showed a lower amylose content in the HC test. In other words, only the HC test, which closely resembles the conventional large deformation test, could not detect the texture difference. The difference, though, was detected in the surface texture in the LC test. 'Hokuriku 149' showed medium overall hardness but the highest surface hardness. Inversely, the large-grained cultivar 'Ohchikara' showed the highest value for the overall hardness and a medium value for the surface hardness. 'Hoshiyutaka' with high amylose content showed the lowest values for both types of stickiness. These results made it clear that the combination of the LC test and the HC test was very effective in differentiating texture. These combined tests were applied to the texture measurement of cooked rice grains which had been decontaminated with low-energy electrons[4], processed using heat pressure ohmic heating[22], developed for quick cooking rice[20], or treated with vinegar[8].

Palatability prediction of *Japonica* rice cultivars based on the texture properties of single cooked milled-rice grains

As explained above, rice palatability is related to cooked rice texture. Statistical models for predicting rice palatability using the developed single-grain method were examined, for *Japonica* rice cultivars with a narrow range of amylose and protein contents[12]. Multiple regression models with the texture parameters as predictors were made to predict some attributes by sensory evaluation such as "overall evaluation", "stickiness" and "softness". The prediction models are shown in Table 1. It was revealed that the model of the LC test gave higher multiple correlation coefficients and can more accurately predict "overall evaluation" by sensory evaluation. Fig. 3 shows the plots for calibration and prediction in the LC test model which indicated that it should be possible, using this surface texture model, to predict palatability to some degree. Shoji and Kurasawa[18] reported that the values obtained using a 'Mido' meter, measuring the surface

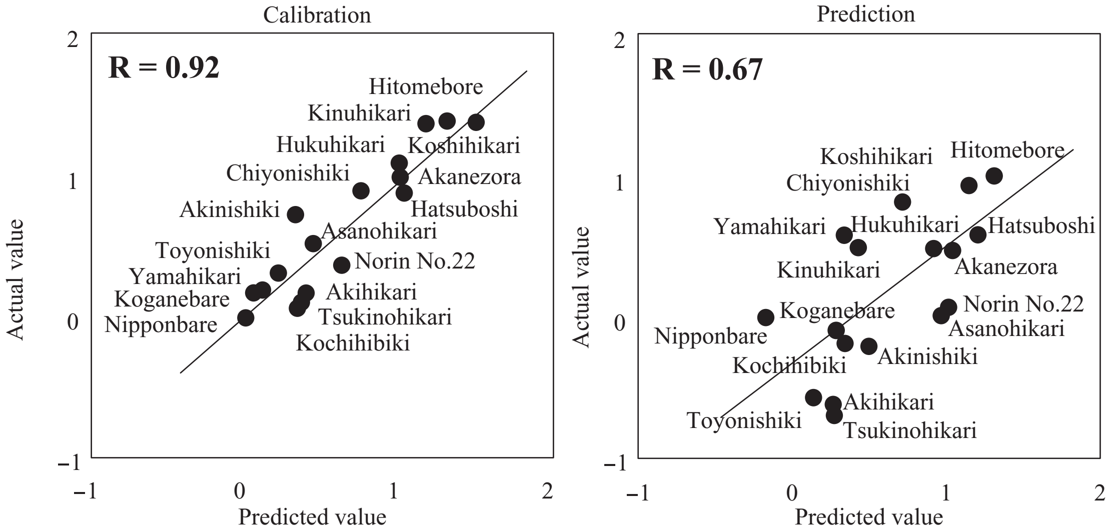

Fig. 3. Scattergrams of calibration and prediction of the multiple regression model for "overall evaluation" by low-compression test

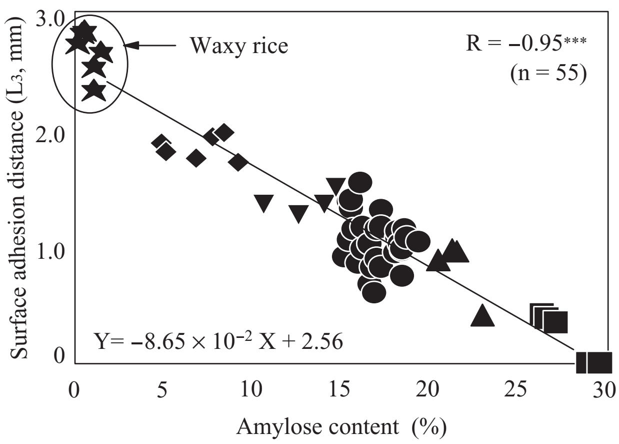

Fig. 4. Relationship between amylose content and surface adhesion distance

***: Significant at 0.1%. Different symbols not enclosed in the circle represent every 5% difference in amylose content of the non-waxy rice.

gloss of cooked rice, indicated a high correlation with the rice palatability. In our study, surface texture gave a more accurate model than overall texture, suggesting that surface texture is an important index of palatability. The surface stickiness parameters were also able to predict the "stickiness" as experienced by sensory evaluation. Significantly, it found that the surface adhesion distance (L_3) was a very important indicator. Fig. 4 shows the relationship between amylose content and the surface adhesion distance[14]. The amylose content revealed a significant correlation with the adhesion distance. The stickier cooked rice grains showed higher values for adhesion distance. That is to say, waxy rice samples gave the highest values. Among non-waxy rice samples, the lower amylose content cultivars gave higher adhesion distance values. A new stickiness parameter, the surface adhesion distance (L_3), can be used to express the stickiness property of the surface layer. There is a trial for predicting this distance by digitalization of DNA bands based on a PCR method[7]. There are many large deformation tests in conventionally used methods. These results indicated that the small deformation test designed to detect surface texture properties is very effective in evaluating rice palatability or stickiness.

Effect of nitrogenous fertilizers on the texture of cooked rice

The protein content of rice grains is affected by the use of nitrogenous fertilizers, and it also has a close relation with rice palatability. It is generally said in Japan that palatability decreases with increased protein content. There is a trend for higher protein content in rice grains to give them a harder texture after cooking. Fig. 5 shows the effect of protein content on the surface hardness and overall hardness, using rice samples with different nitrogen fertilizer applications in the same *Japonica* cultivar[13]. The amylose contents indicated a positive correlation at 1% significance with the overall hardness that varied with the cultivar rather than with type of fertilizer application. More specifically, 'Hinohikari', which has the lowest amylose content, had the lowest overall hardness. 'Reiho', which has the highest amylose content, showed the highest values. It is clear that the overall hardness that varied according to cultivars depends greatly on amylose content. On the other hand, protein content indicated a positive correlation with surface hardness. The surface hardness increased with higher protein content in each cultivar and differed according to the treatment rather than cultivar. Protein is mainly distributed in the outer layer of the grain. It is quite likely that the hardening of the surface of cooked grains occurred as a result of increased accumulation of protein in the surface layer due to the use of nitrogenous fertilizers. It is believed that the proteins in the outer layers prevent water absorption and thus expansion of the grains during cooking, with the net result that the surface layer hardens. It is clear that the surface hardness and the overall hardness are greatly influenced by protein content and amylose content, respectively. Conversely, it was also found that both types of hardness played a major role in differentiating these components. The relationship between hardness and eating quality is shown in Fig. 6. Both

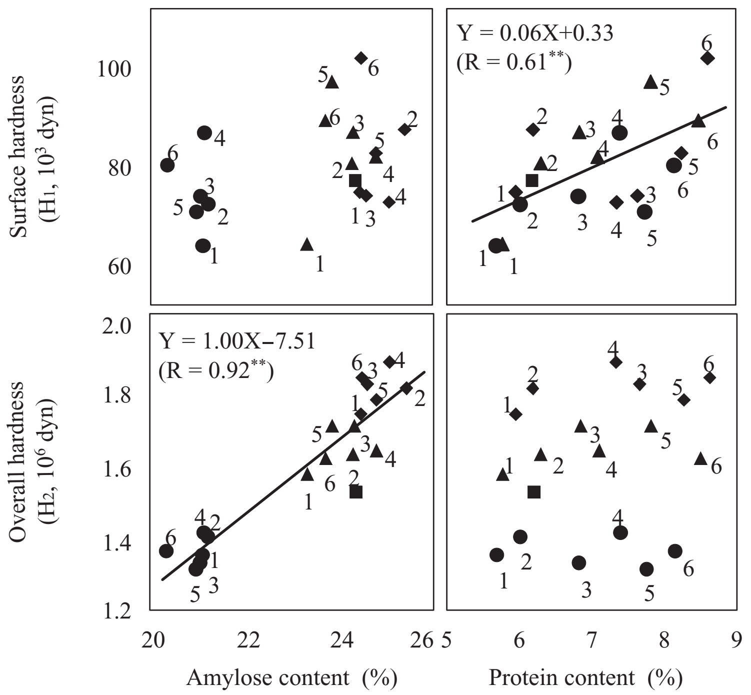

Fig. 5. Relationship between rice components and hardness among different fertilizers applied to the same *Japonica* rice cultivars

●: Hinohikari, ◆: Reiho, ▲: Yumehikari, ■: Nipponbare. Values next to each symbol indicate the relative amount of nitrogen fertilizer supplied to each cultivar in increasing order (1 to 6). **: Significant at 1%.

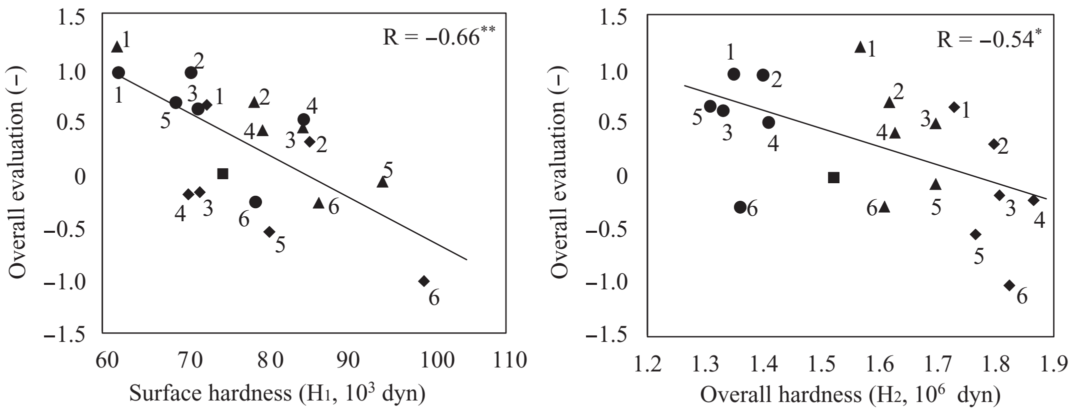

Fig. 6. Relationship between palatability and hardness among different nitrogen fertilizers applied to the same *Japonica* rice cultivars

●: Hinohikari, ◆: Reiho, ▲: Yumehikari, ■: Nipponbare. Values next to each symbol indicate the relative amount of nitrogen fertilizer supplied to each cultivar in increasing order (1 to 6).

* & **: Significant at 5% and 1% .

types of hardness indicated a negative correlation but the value was slightly higher for the surface hardness. Surface hardness was a clear indicator of variation in eating quality within each cultivar. The overall hardness appeared to express the eating quality of each cultivar. Therefore, it was concluded that the surface hardness is more suitable for discriminating protein content or palatability in the same cultivar, and that the overall hardness is a good indicator of the inherent traits of each cultivar.

Rice component determination by multiple regression models based on the texture properties

Amylose content and protein content of the main components of rice are very important for determining the use of grains in rice-based food industries. These components are basically determined by chemical methods but several non-destructive analysis methods have been developed using near-infrared spectroscopy methods[1,16]. The author has described how some texture properties are related to these components. Therefore, calibration models based on the texture properties were examined to enable accurate prediction of these components, using multiple regression analysis. Table 2 shows the calibration models for amylose content determination using the single-grain method with the LHC test and the conventional three-grain method[15]. Among samples covering a wide range of amylose content (0 to 30%), the model for the single-grains method indicated a higher R^2 and lower SEC in calibration for amylose content than seen in the other method. The former model also indicated a lower SEP in validation and clearly revealed better precision. Almost all non-glutinous rice grains, which are usually distributed and consumed in Japan, are low in amylose content, and the range of amylose content is narrow compared to those in other Asian countries[6]. It is

Table 2. Calibration models for determination of amylose content (0 to 30%) based on the texture properties and prediction accuracy for the validation set

Calibration model	Calibration (n = 134)		Validation (n = 67)		
	R^2	SEC	R^2	SEP	RPD
1. Multiple regression model by single-grain method (LHC Test) with a Tensipresser Model 1: $Y = -3.79(L_6) + 1.26 \times 10^{-6}(A_4) + 9.82(-H_1/H_1) - 7.47(L_3) + 24.16(L_2) + 14.93(-H_2/H_2) - 8.74 \times 10^{-6}(A_5) + 324.87(L_5) - 40.76$	0.95	1.77	0.94	2.07	3.80
2. Multiple regression model by three-grain method with a Texturometer Model 2: $Y = -536.38(A_3/A_1) + 234.13(A_3) - 42.40(-H_2) + 39.81(-H_1/H_1) - 5.23(A_2) + 40.54$	0.86	2.95	0.86	3.20	2.46

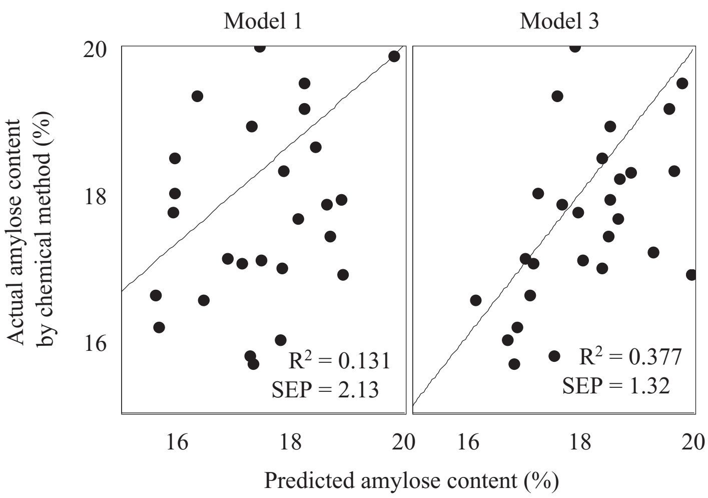

Fig. 7. Prediction for unknown samples within a narrow range of amylose content (15 to 20%) using two kinds of models on the basis of an LHC test (n = 47)

Model 3 is a multiple regression model made with only samples of 14–21% amylose content (n = 85).

$Y = -3.47(L_3) - 6.57 \times 10^{-5}(A_1) + 1.44 \times 10^{-4}(A_2) + 8.46 \times 10^{-6}(A_6) - 75.87(A_6/A_4) - 9.74 \times 10^{-6}(H_2) - 2.42 \times 10^{-4}(H_1) + 42.12$

Table 3. Calibration models for determination of protein content (5 to 9%) based on texture properties and prediction accuracy for validation samples

Calibration model	Calibration (n = 134)		Validation (n = 67)		
	R^2	SEC	R^2	SEP	RPD
1. Multiple regression models by single-grain method (LHC Test) with a Tensipresser					
Model 4: Surface physical properties $Y = -7.76(L_1) + 10.28(-H_1/H_1) + 2.08 \times 10^{-5}(H_1) - 4.43 \times 10^{-5}(A_2) - 2.69 \times 10^{-4}(-H_1) + 6.47$	0.40	0.71	0.39	0.71	1.25
Model 5: Overall physical properties $Y = -2.60(L_4) + 11.77$	0.09	0.86	0.21	0.78	1.14
Model 6: Surface and overall physical properties $Y = -18.21(L_1) + 8.25(-H_1/H_1) + 2.39 \times 10^{-4}(H_1) - 7.34 \times 10^{-5}(A_2) - 2.12 \times 10^{-4}(-H_1) + 7.82 \times 10^{-7}(A_4) - 35.28(L_5) + 12.88(L_2) + 13.55$	0.45	0.69	0.47	0.69	1.29
2. Multiple regression model by three-grain method with a Texturometer					
Model 7: $Y = -8.48(A_4) - 0.812(A_2) + 9.46$	0.17	0.82	0.12	0.84	1.06

essential to develop highly-accurate models for non-glutinous samples that fall within a narrow range of amylose content. Fig. 7 shows the prediction result of the two models obtained by the LHC test for the unknown samples in the narrow range (amylose content: 15 to 20%). Model 1 revealed the best accuracy among the wide range of samples, but resulted in lower accuracy for the narrow range of samples than Model 3. Therefore, Model 1 should be basically used to determine the amylose content of unknown samples. However, we consider that it is better to first use Model 1 for the narrow range (15 to 20%) samples and then to make a precise calculation using Model 3. Table 3 shows the calibration models for protein content. In the LHC test, Model 4, with only surface attributes, possessed higher prediction accuracy than Model 5, with the overall attributes only. Model 6 possessed the highest accuracy and also took account of numerous surface attributes as predictors. Model 7, using the conventional three-grain method, had a lower coefficient of determination than Model 6. A comparison between the components shows the value for RPD to be higher in amylose content than in protein content, revealing that amylose content can be more accurately predicted. As described above, the single-grain method (LHC test) was able to determine rice components more accurately than the three-grain method, with the accuracy being markedly better with respect to amyolse content.

Conclusions

A single-grain method for multi-texture measurement of cooked milled-rice grains was examined. Rice quality evaluation techniques were studied on the basis of this method. The low- and high-compression (LHC) test, measuring surface and overall texture properties (25% and 90% compressions for the cooked grain thickness), was effective in enhancing the classification accuracy of the texture. The multiple regression model of the surface texture properties indicated a higher prediction accuracy for palatability than that of the overall texture properties. It was suggested for the first time that the palatability of *Japonica* rice cultivars is closely correlated with their surface texture properties. A new stickiness parameter, the surface adhesion distance (L_3), closely correlated with amylose content, was used to express the stickiness property of the surface layer. Concerning the effect of protein content on the texture among samples of the same cultivars given different nitrogen fertilizers, the overall hardness of the high compression test differed according to rice cultivar rather than fertilizer treatment, and was positively correlated with the amylose content. The surface hardness showed a higher correlation with protein content than the overall hardness. Surface hardness could be used for distinguishing the protein content and the palatability as affected by the nitrogen fertilizer applications. Finally, the multiple regression model of the single-grain method with the LHC test was able to predict amylose content more precisely.

As mentioned above, it was possible, using the LHC test single-grain method, to evaluate not only grain texture but also many other qualities such as protein content, palatability and amylose content. Since the single-grain method can evaluate these qualities in small-scale samples, it is potentially very useful for application in the pre-harvest field, for example, in rice breeding and also for post-harvest grains for food industry purposes. In particular, the introduction of the low compression test will make a major contribution to better accuracy and extend the fields to which rice quality evaluation may be applied. It would be desirable in future years to further proceed with a series of operations from measuring to data analysis and to upgrade the developed multiple regression models at stated periods by adding the texture data.

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