Multiple Measurements of Physical Properties of Individual Cooked Rice Grains with a Single Apparatus

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ABSTRACT

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Multiple measurements of physical properties of cooked rice grains were applied to 55 rice samples with waxy to high amylose contents using a single apparatus (Tensipresser). The multiple measurements consisted of low, high, and continuous progressive compression tests (LC, HC, CPC). The overall hardness (H_2) determined by the HC test, and the surface hardness (H_1) determined by the LC test, were used as indices to classify the samples into the several groups corresponding to amylose content. The surface hardness was more suitable than the overall hardness for differentiating the effect of protein contents. The difference of stickiness among the cooked rice samples could be detected by the surface adhesion distance (L_3) using the LC test. The ratio of elastic limit length (RELL), estimated by the back pressure curve on the CPC test, increased with amylose content. These three tests were meaningful in characterizing the physical properties of cooked rice samples with waxy to high amylose contents.

As rice is consumed mainly as whole cooked grains in Japan, the texture of cooked grains is very important for the palatability of rice. Many studies have been conducted on the measurement of cooked rice texture. Okabe (1979) developed the three-grain method with a Texturometer, in which three cooked rice grains were compressed at large deformation (0.2-mm clearance, ≈80–95% compression ratio). The three-grain method is often employed in Japan to quantify the hardness and stickiness of cooked rice using a Texturometer as well as a rheometer (Ikeda et al 1997). Perez et al (1993) reported a puncture test or an OTMS extrusion test with an Instron tester. Rousset et al (1995) determined the thickness, firmness, and elastic recovery of cooked rice with a viscoelastograph. Champagne et al (1998) reported a method in which cooked rice grains were compressed and arranged in a single-layer on the base plate with a texture analyzer. A dynamic elasticity test was also applied for cooked rice texture measurement (Yoshii et al 1993, Otobe et al 1995). As numerous objective methods with various kinds of apparatus were developed, there were reports about the compatibility of data among those methods (Juliano et al 1981, Ohtsubo et al 1990). We have already reported (Okadome et al 1996) the optimum measuring conditions for the multiple measurements of physical properties of individual cooked rice grains to clearly differentiate nonwaxy cooked rice texture, making the best use of the feature of the Tensipresser instrument as one of the advanced apparatuses.

In the present study, we applied a Tensipresser to the multiple measurements of physical properties of the cooked rice grains from waxy to high amylose contents. The object of this study was to propose the suitable indices to clearly differentiate these various rice samples based on physical properties

MATERIALS AND METHODS

Fifty-five rice samples, produced in 1994 at the National Agriculture Research Center (Ministry of Agriculture, Forestry and Fisheries of Japan, MAFF) and five regional (Hokkaido, Tohoku, Hokuriku, Chugoku, Kyushu) National Agricultural Experiment Stations, were subjected to the experiments. All brown rice samples were milled to yield 90–91% with a friction-type rice miller (VP-31T, Yamamoto Co. Ltd.).

Analyses of Chemical Components

Moisture content of milled rice was measured by the oven-dry method, drying the flours for 1 hr at 135°C. Protein content was estimated N × 5.95 using the Kjeldahl method. Amylose content was determined by the iodine colorimetric method (Juliano 1971). Potato amylose (Sigma Chemical Co.) as standard amylose and waxy rice starch (Shimada Chemical Industry Co. Ltd.), defatted and deproteinized as standard amylopectin, were submitted to the calibration formula for amylose determination.

Cooking Method

The milled rice samples (10 g) were added with 16 g of water in an aluminum cup (55 × 40 × 55 mm). After soaking for 1 hr, the five milled rice samples were cooked in an electric rice cooker (RC183, Toshiba Co. Ltd.). To prevent moisture loss after cooking, all cups were covered with an outer sheet of aluminum foil and an inner sheet of paper for the absorption of excess vapor, and sealed in a plastic and airtight vessel. The cooked rice samples were kept in the vessels for ≈2 hr at room temperature (25°C) and then measured.

Measurement of Physical Properties

Three compression tests, low (LC, 25% compression), high (HC, 90% compression) and continuous progressive compression (CPC), were used for multiple measurements of physical properties of individual cooked rice grains. A Tensipresser (Myboy System, Taketomo Electric Co., Japan) was used as a measuring apparatus. Table I shows the measurement conditions of the instrument. Figure 1 illustrates the data analyses of force-time curves on these tests.

The physical properties of hardness and stickiness in a surface layer of a single cooked rice grain were measured using the LC test. The compression ratio of LC test was 25%, which caused a small deformation in the thickness of grain. The aim of LC test was to detect the differences of hardness and stickiness among the samples at the outer surface layer of cooked rice grains. The physical properties of an overall layer of a single cooked rice grain were measured using the HC test. The grain was compressed completely at 90%, with large deformation as proposed by Tsuji (1981). The HC test was similar to the conventional method using a Texturometer (Okabe 1979) at the point of the large deformation. The combination of LC and HC tests was adopted to evaluate the hardness and the stickiness of cooked rice more precisely. The physical properties measured by the LC and HC tests were analyzed based on texture profile analysis (TPA) (Szczeniak 1963, Bourne 1978). The hardness and stickiness measured by LC test were used as the surface hardness and surface stickiness, while HC test measured the overall hardness and overall stickiness.

The measurements and data analyses of the CPC test were different from the first two compression tests. This test has a back

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pressure curve. The original CPC test using a Tensipresser was developed for the evaluation of meat tenderness (Yanagihara et al 1995). Measuring conditions were developed for CPC testing of cooked rice texture. This method was also applied to the texture measurement of Korean noodle (Toyama and Taneya 1998). The single cooked rice grain was compressed progressively at the continuous amplitude of vibration (Fig. 1). The compression force at the immediate time when the plunger deformed the grain (D_1: 0.1 mm) was detected continuously on the compression curve. The back pressure force at the immediate time when the plunger returned (D_2: 0.25 mm) was detected continuously on the back pressure curve.

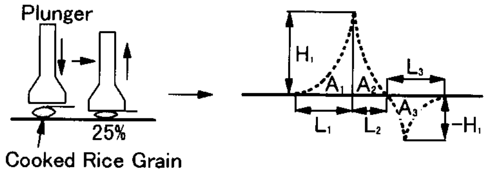
All of the measurements were made using the same load cell, bite speed, plunger, and sample stage. Endo et al (1980) improved the sensing arm of Texturometer to detect more sensitively the stickiness that was detected weakly by the same strain gauge, compared with the hardness. Then, the sensitivity of negative gain was also adjusted to be higher than that of positive gain on the all tests. Each datum of physical properties for the samples was calculated as the average of data of 10 individual grains.

The three-grain method (Okabe 1979) measuring the physical properties of three cooked rice grains at a large deformation (0.2-mm clearance) by a Texturometer (Zenken Co., Japan) was used as a control.

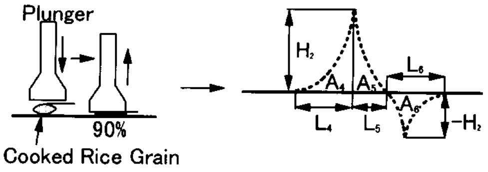
RESULTS AND DISCUSSION

Chemical Components of Milled Rice Samples

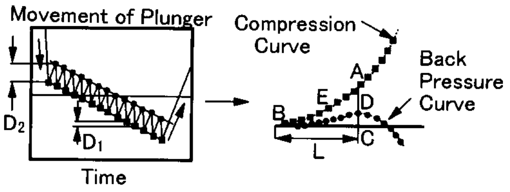
The components of all milled rice samples were 13.1–17.1% (wb) moisture, 4.0–9.5% (db) for protein, and 0.2–29.7% (db) for the amylose content, respectively (Table II).



Low Compression Test (LC Test)



High Compression Test (HC Test)



D_1 (Added Value) = 0.1mm
D_2 (2nd Distance) = 0.25mm
Elastic Limit Length = L
Toughness = Area of AEBC
RELL = Ratio of L to Grain Thickness

Continuous Progressive Compression Test (CPC Test

Fig. 1. Data analyses on multiple measurements of physical properties determined using a Tensipresser.

Differentiation of Hardness and Stickiness

The positive peak values (H_1, H_2) were used as the indices of hardness on each test (Fig. 2). The overall hardness (H_2) measured by the HC test revealed a positive single correlation at 0.1% significance with the surface hardness (H_1) by the LC test for all samples ($r = 0.79$). Amylose content has a correlation with hardness of cooked rice (Juliano et al 1981). In the two compression tests we adopted, the hardness of cooked rice was divided into surface hardness and overall hardness. Both had a positive correlation with the amylose content (surface hardness $r = 0.77$, overall hardness $r = 0.80$). The amylose content affected overall hardness and surface hardness. The overall hardness was more diversified than surface hardness among the samples with the highest amylose contents (group 6). The samples of group 2 showed similar overall hardness, but were different in surface hardness. Surface hardness and overall hardness in group 4 both showed the highest diversification among all groups. In comparison, mean values for each group showed 5 had the highest surface hardness and 6 had the highest values for overall hardness. Group 1 waxy rice samples showed the lowest value for both. The relationship between the protein content and hardness for all samples is shown in Fig. 3. The protein contents revealed a positive single correlation with each hardness. The correlation coefficient of surface hardness ($r = 0.51$) was higher than that of overall hardness ($r = 0.35$). Therefore, surface hardness was more suitable to detect the effect of protein than overall hardness. The protein of milled rice is distributed more in the outer layer of the grain (Barber 1972), so it was considered that protein content affected surface hardness of cooked rice grains more than overall hardness. The effect of protein content and amylose content on the surface hardness in several samples with similar overall hardness at 140–150 ($\times 10^4$ dyn) is shown in Fig. 4. Although the samples were similar in overall hardness, surface hardness increased with protein contents. Surface hardness had a higher positive correlation with the protein contents ($r = 0.80$) than amylose content ($r = 0.44$). Surface hardness was more useful in determining the difference of protein contents in samples with similar overall hardness. The results of this study showed that overall hardness and surface hardness were meaningful in

TABLE I
Conditions of Tensipresser Measurement[a]

	LC Test (%)	HC Test (%)	CPC Test (mm)
Compression ratio	25	90	· · ·
Clearance	· · ·	· · ·	0.10
Added value (D_1)	· · ·	· · ·	0.10
2nd distance (D_2)	· · ·	· · ·	0.25
Bite time	1	1	29
Sensitivity of gain			
Magnificant of gain	5	1	5
+	1	1	1
–	5	2	10

[a] Low (LC, 25% compression), high (HC, 90% compression) and continuous progressive compression (CPC) tests. Load cell: max. 5 kgf; plunger shape: flat type (3.0 cm dia.); plunger material: aluminum (alumite coating); sample stage: aluminum (alumite coating); plunger speed: (2.0 mm/sec).

TABLE II
Components of Milled Rice Samples

	n	Moisture (% wb)	Protein (%db)	Amylose (%db)
Group 1 (waxy rice)	6	14.2–17.1	5.1–6.3	0.2–1.5
Group 2 (AC < 10%)[a]	6	14.1–16.2	4.0–7.5	5.0–9.3
Group 3 (10% < AC < 15%)	4	13.6–14.5	5.6–6.0	10.7–14.8
Group 4 (15% < AC < 20%)	30	13.1–16.1	5.4–5.8	15.2–19.4
Group 5 (20% < AC < 25%)	4	13.3–14.1	7.0–9.5	20.6–23.1
Group 6 (25% < AC < 30%)	5	13.9–15.1	5.3–7.1	26.6–29.7

[a] Amylose content (AC, %db) = effect of moisture and protein has been subtracted.

characterizing the hardness of cooked rice grains. Amylose content also influenced both types of hardness; surface hardness was more suitable for observing the effect of protein contents than was overall hardness.

The Tensipresser HC test was similar to the conventional Texturometer method with three cooked rice grains (Okabe 1979) at the point of the large deformation. Figure 5 compares the physical properties of the conventional method and the HC test. The hardness and stickiness of three grains by the Texturometer method were shown as the positive and negative peak heights on the first bite curve. Those of a single grain by the Tensipresser corresponded to the positive and negative peak heights (H_2, $-H_2$) on the profile curve in the HC test. The Tensipresser hardness revealed a high correlation with the Texturometer hardness when using only glutinous rice samples (Ohtsubo et al 1998). This study included not only glutinous rice samples but also waxy rice samples and also showed a positive correlation at 0.1% significance ($r = 0.94$). Therefore, the HC test measuring a single grain could obtain the same hardness results as the three-grain method using a Texturometer. The Tensipresser could be used to differentiate the stickiness of rice samples of high amylose contents (group 6) more clearly than the Texturometer. However, group 1 and group 2, which are sticky rice samples, showed high values for the stickiness with the Texturometer but medium values for the stickiness with the Tensipresser. The differentiation of stickiness among all groups seemed to be difficult by only the negative peak ($-H_2$) on the HC test of the Tensipresser.

Both the adhesion force ($-H_1$) and adhesion distance (L_3) on surface stickiness by the LC test were suitable indices to predict the stickiness by sensory evaluation of Japonica rice cultivars (Okadome et al 1998). The relationship between amylose content and three parameters of surface stickiness obtained by the LC test is illustrated with all rice samples (Fig. 6). The amylose content revealed a negative single correlation with the adhesiveness (A_3) and also with the adhesion distance (L_3). The correlation coefficient with the adhesion distance ($r = -0.93$) was higher than that with the adhesiveness ($r = -0.70$) or the adhesion force ($r = 0.77$). The adhesion distance tended to increase with the decrease of amylose content. The stickier cooked rice grains showed higher values of

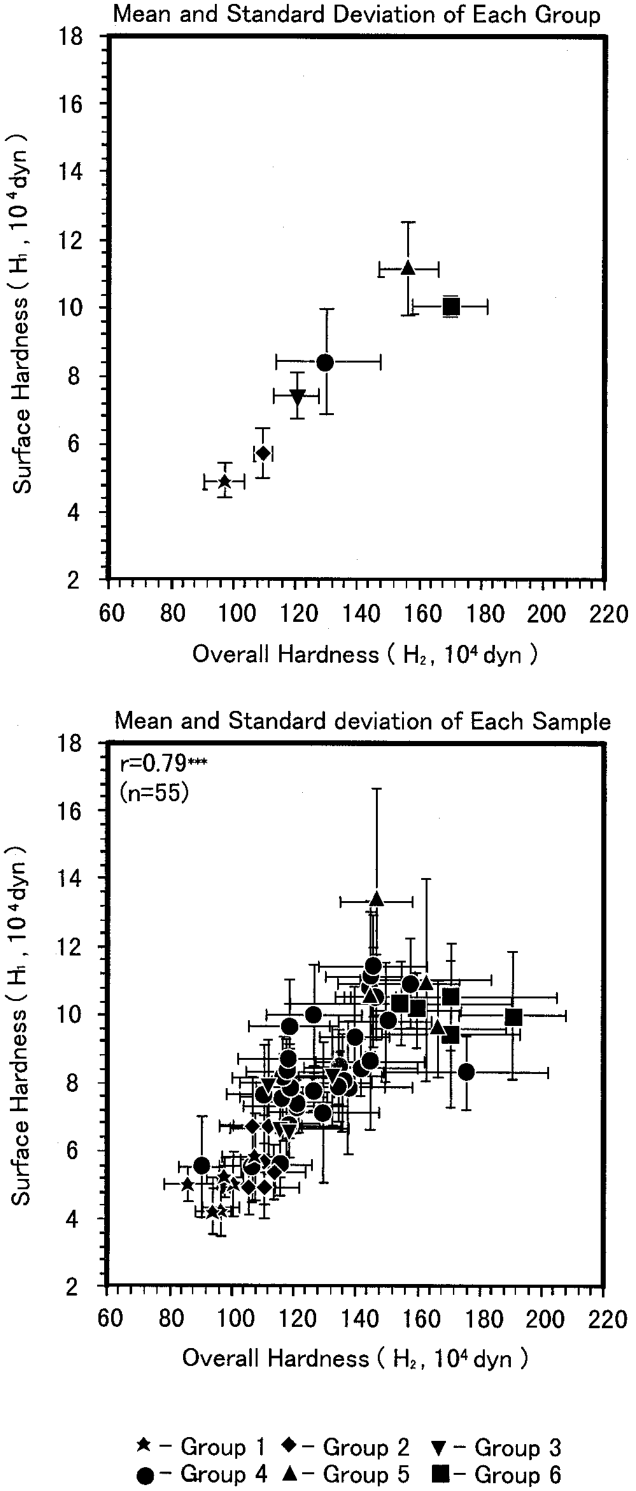


Fig. 2. Hardness of cooked rice grains determined by low and high compression (HC and LC) tests. *** = $P < 0.1\%$.

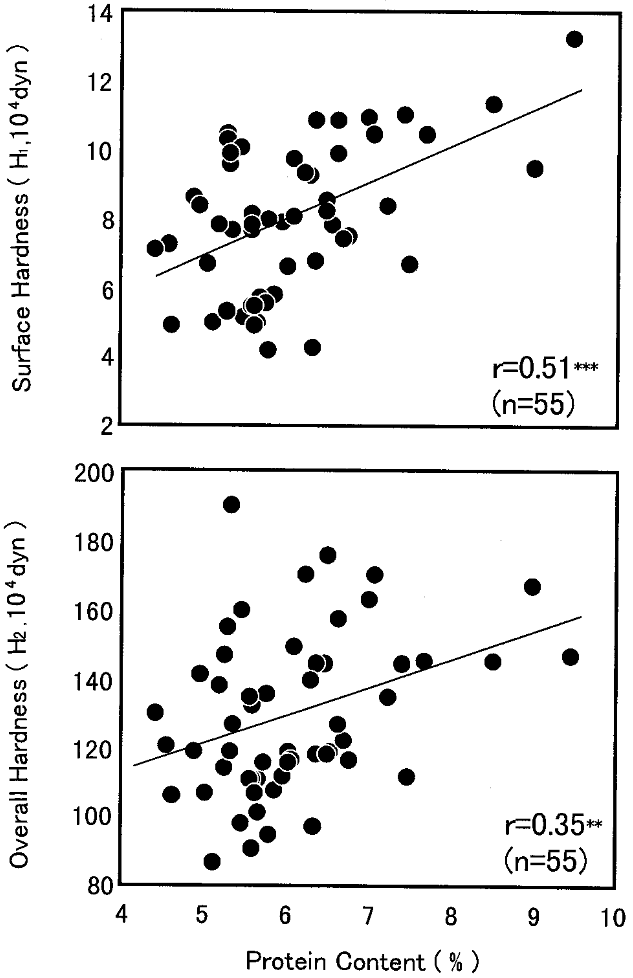


Fig. 3. Relationship between protein content and hardness of cooked rice grains. ** and *** = $P < 1\%$ and 0.1%, respectively.

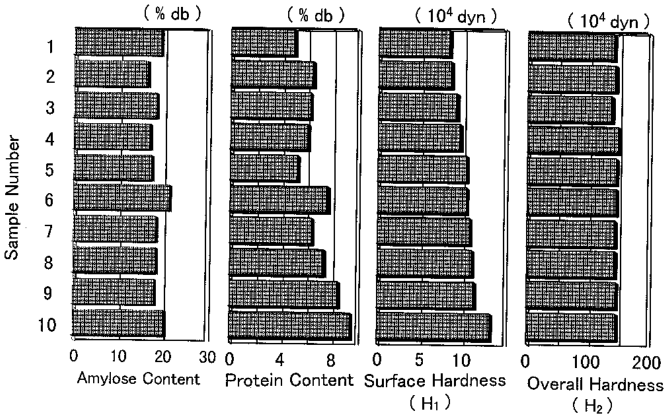


Fig. 4. Effect of proten content and amylose content on surface hardness among samples of similar overall hardness. Samples 1–10: Chugoku 113, Hokuriku 162, Hinohikari, Hokuriku 153, low glutelin rice, hokkai 278, Saikai 213, Kitahikari, Hokkai 269, Hokkai 279.

adhesion distance. Group 1 waxy rice samples had the highest adhesion distance. Among nonwaxy rice samples, group 2 with the lowest amylose content had the highest adhesion distance, and group 6 with the highest amylose content had the lowest adhesion distance. Stickiness measured by the Texturometer could not detect differences among groups 1, 2, and 3 as clearly as the surface adhesion distance. The peak area on the stickiness curve has usually been used as an attribute to quantify the stickiness of cooked rice in the TPA method. The surface adhesion distance (L_3) of the LC test was a more suitable index to classify the difference in stickiness among the cooked rice samples than the other parameters of the LC test or the overall stickiness ($-H_2$) of the HC test.

The combination of the HC test and the LC test was effective in detecting the subtle differences of hardness and stickiness in cooked rice. These combined tests were also effective for the discrimination of cooked rice texture decontaminated with low-energy electrons (Hayashi et al 1998). Cooked rice texture has been mainly assessed by the physical parameters measured by a conventional large deformation test such as the three-grain method. Our results showed that the physical properties of the surface layer of cooked rice grains measured by the small deformation LC test were also important in differentiating cooked rice texture.

Physical Properties of Cooked Rice Grains by CPC Test

The force-time curves obtained using the CPC test are illustrated for three typical rice samples (Fig. 7). In the back pressure curve of the waxy rice, pressure showed a slight increase initially, and then reached the maximum, and finally the pressure changed from positive to negative. The back pressure of low amylose rice showed a pattern similar to waxy rice, but the maximum of back pressure was higher. For high amylose rice, the back pressure tended to increase continuously from initial to final point, and the stickiness was not detected. The elasticity of cooked rice grains was considered to be the positive back pressure curve. Therefore, in waxy and low amylose rice grains, the decrease of back pressure after the maximum point seemed to be closely related with the breakage of the inner structure of the cooked rice grains. We believe that the high amylose cooked rice maintained elasticity to the final deformation and had less destruction of structure than either the waxy or low amylose rice. We have already reported that the ratio of elastic limit length (RELL %, the ratio of L to the thickness of cooked rice grain) for excellent eating quality Japonica rice tended to be small (Okadome et al 1996). The RELL increased with the increase of amylose content (Fig. 8). The slope of the regression line for the samples with 0–20% amylose content was lower than that for the samples with 20–30% amylose content. It was noted that the RELL was closely related to amylose content. The RELL also revealed a higher correlation with the overall hardness (r = 0.80) than with the surface hardness (r = 0.55). The diversification of overall hardness among the rice samples had a close relationship with the elasticity or destruction of structure of cooked rice grain.

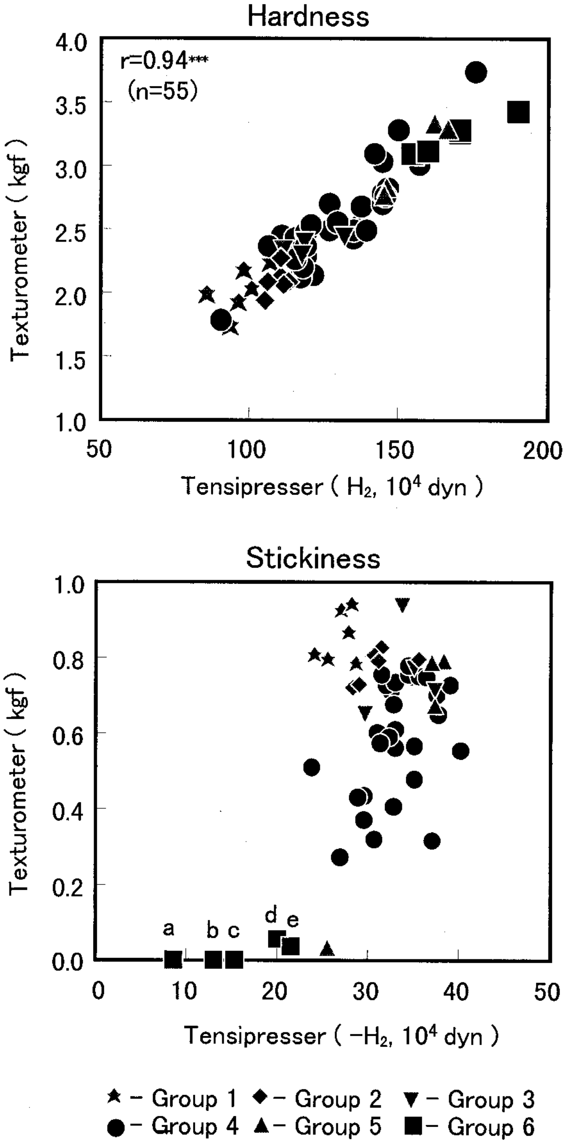


Fig. 5. Comparison of physical properties between Texturometer (three-grain method, 0.2-mm clearance) and Tensipresser high compression test (single-grain method). Samples a–e: Hokuriku 142 (amylose content [AC] 29.7%), Kounosu 309 (AC 29.0%), Chugoku 140 (AC 27.1%), Hoshiyutaka (AC 26.4%), Chugoku 134 (AC 26.6%). *** = $P < 0.1\%$.

CONCLUSIONS

The suitable indices to differentiate rice samples from waxy to high amylose contents were selected from the attributes based on the multiple measurements of physical properties of the cooked rice grains. The overall hardness (H_2) of the HC test and the surface hardness (H_1) of the LC test were useful in classifying the samples into several groups based on amylose content. The surface hardness was also more suitable for differentiating the effect of protein contents than was overall hardness. Surface hardness was especially more effective for samples of similar overall hardness. The difference in stickiness among cooked rice samples could be

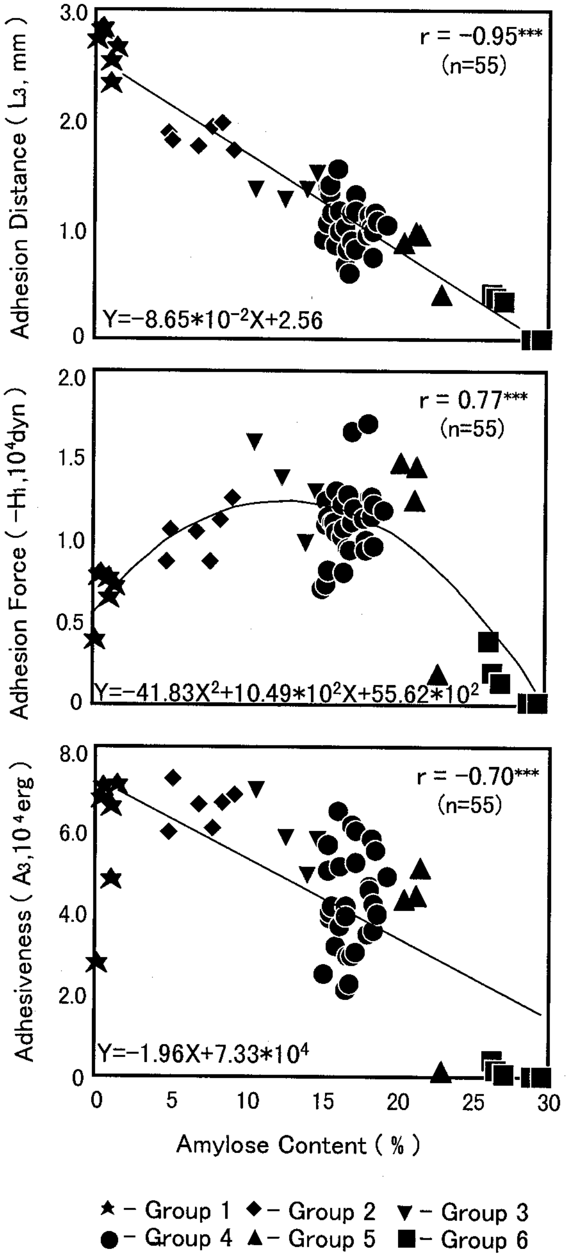


Fig. 6. Low compression (LC) test results showing the relationship between amylose content and three parameters of surface stickiness. *** = $P < 0.1\%$.

detected by the surface adhesion distance (L_3) of the LC test. The combination of the HC test and the LC test was effective in determining the differences of hardness and stickiness of cooked rice grains. The maximum of back pressure curve obtained by the CPC test differed among rice samples of different amylose contents. The RELL by the CPC test was closely related to the amylose contents and overall hardness.

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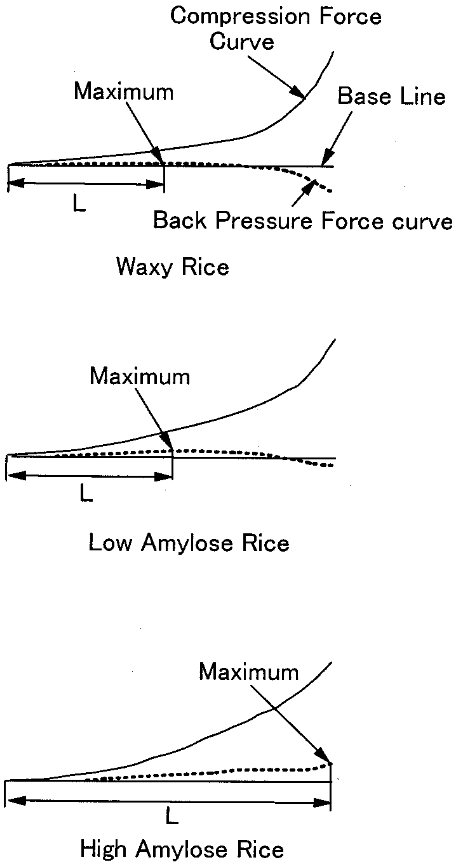

Fig. 7. Profile curves of cooked rice grains from continuous progressive compression testing. Elastic limit length (L) = distance to maximum on back pressure curve.

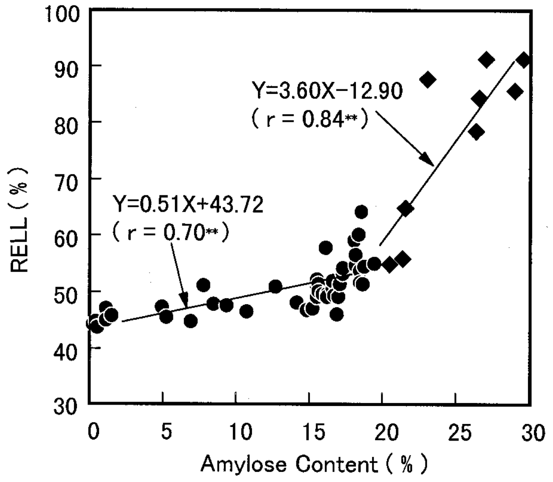

Fig. 8. Relationship between amylose content and ratio of elastic limit length (RELL) to grain thickness from continuous progressive compression testing. ** = $P < 1.0\%$.

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