Quality Evaluation of Rice Crackers Based on Physicochemical Measurements

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The processing suitability as a material for rice crackers was characterized in the present study, based on physicochemical measurements and sensory testing of high-quality premium rice, low-amylose rice, japonica- indica hybrid rice, and red rice as the rice cultivar samples. Puffed rice crackers were prepared and the relationship between the physicochemical properties of the rice grains and the quality of the resulting products was investigated. It was possible to estimate the physical properties of a rice cracker by using multiple-regression analysis based on the chemical components, pasting properties and physical properties of the constituent rice. A formula for estimating the amyllose content of the constituent rice was developed from the results of physicochemical measurements of the rice crackers. We assayed the quality of commercial rice crackers and examined the deterioration during the storage by measuring the physicochemical properties. The hardness and fat acidity of crackers increased markedly during storage for 20 d at 35°C. The novel method of a one-bite test with a Tensipresser was useful to assay the quality of a rice cracker and made it possible to evaluate the quality deterioration of the rice cracker during storage.

Key words: rice cracker; Tensipresser; physical property; sensory test; quality

Rice is one of the most important crops in the world together with wheat and corn. World production of rice is expected to be 450 million metric tons (milled basis) in 2011/2012, with Japan producing 7.68 million metric tons. Rice is used as table food and for various food processing applications such as sake wine, rice snacks and rice cake. About 10% of the total rice production in Japan is consumed as the material after rice processing and 223 thousand tons of rice crackers being produced in Japan in 2010.1,2

The rice-based foods have also been diversified and such convenient products, as frozen cooked rice, retort-pouched cooked rice and aseptic cooked rice, have increased markedly. However, the total rice consumption is decreasing year by year in Japan. It is necessary to provide new characteristic rice cultivars or high-quality rice products which can satisfy the requirements of the food industry and consumers, and lead to increased rice consumption.2-5

Rice crackers are one of the traditional rice products in Japan and other Asian countries and their consumption has recently been increasing in USA, Europe, Australia and China. Rice crackers have been accepted by many consumers because they are palatable, low in calorie, and can be preserved for a long time. The revision of the Act of JAS (Japanese Agricultural Standards) in 2003 and the enforcement of the “Rice Traceability Law” in 2011 makes it obligatory for the rice cultivars, location and year of production to be described on the packaging of milled rice, brown rice, rice flour, and various kinds of processed rice products including rice crackers. It is therefore indispensable to have techniques, to identify or differentiate them by objective methods.6

Traditional baked Japanese rice crackers include senbei and arare.7-9 Arare is a cracker made from boiled waxy rice, pounded into rice cake with a mochi pounding machine and stored at 2–5°C for 2–3 d to harden, before cutting, drying to 20% moisture content, and baking at 200–260°C. Sesame seeds, pieces of dried seaweed, peanuts, pulverized shrimp, cheese, or spices can be mixed with the rice dough if desired. Senbei is a cracker-like snack made from cooked non-waxy rice flour, which is kneaded and rolled into sheets, cut, dried at 70–75°C to a 10–12% moisture content, and finally baked at 200–260°C.7-9 The degree of starch gelatinization expansion rate and degree of starch retrogradation are important factors for the quality of rice crackers.10

Arare expands more than senbei during baking and produces a softer texture, and can be easily dissolved while eating. Senbei is harder and rougher than arare. The classification of rice crackers based on quality shows Uki-type crackers to have a higher specific volume (above 4.0 mL/g), and Shime-type ones to have a lower specific volume ratio (3.5–4.6 mL/g).7-9

Japanese rice crackers are produced by many procedures, and the development of novel techniques to stabilize the quality of rice crackers therefore important. Saito et al. have conducted research into the characteristics of rice starch by an X-ray analysis for its change during the manufacturing procedures and by an amylograph for the degree of gelatinization.10,11 The degree of retrogradation of starch, during and after the manufacturing operation has also been evaluated by amylography.10

As examples of rice crackers produced in Asian countries, Malao (a rice-based snack in Taiwan),9 gangjung (a traditional Korean oil-puffed snack),12 and fried rice-black gram dough13 have been reported to be popular in each country.

Extrusion cooking is another dominant processing method for snack foods, particularly, in Europe and

Abbreviations: Max vis, maximum viscosity; Min vis, minimum viscosity; Final vis, final viscosity; Max stress, maximum stress

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North America, which is used to modify the functional and digestible characteristics of cereal grains due to its low cost and capability for continuous processing.14–18 Such extruded cereal grains, as wheat, corn, millet, and rye have been tested for their digestibility and palatability.22

The ease of ingestion and palatability of rice crackers for aged people have been studied by compression testing, electromyograph (EMG) recording of the masticatory muscles and sensory evaluation.19 Although several attempts have been made to classify the hardness of rice crackers based on their physical properties and sensory evaluation, such attempts have revealed that the physical properties of rice crackers evaluated by a single physical measurement did not completely match the result of the sensory evaluation.19,20 Takahashi et al. have combined two kinds of measurement, of density measured as the specific volume and of maximum rupture force measured with a creep-meter, which showed high correlation with the rating by a sensory evaluation.20

Nakagawa et al. have studied the method of sun drying rice crackers, and reported that the flavor and texture of rice crackers were both influenced by the drying method (sun drying or artificial drying).21 It therefore, seems very important and meaningful to develop a novel and simple method to evaluate the quality of rice crackers, which matches well with the results of a sensory evaluation.

Yamada et al. have studied the suitability of newly-developed rice cultivars for processing rice crackers and proposed that the pasting properties could be good indices for the expansion of rice crackers.22 It is necessary to elucidate the relationship between the properties of the rice material and the qualities of the rice cracker product to enhance the consumption of rice crackers by using newly-developed rice cultivars.

Although it is well known that rice crackers can be stored for a long period because of their low moisture content, their palatability gradually deteriorates during storage. We carried out a storage test of commercial rice crackers and examined their quality deterioration during storage. We have already reported novel methods to measure the fat acidity23 and physical properties24 of rice during storage and we used these methods for detecting the quality deterioration of rice crackers during storage.

Materials and Methods

Materials. Japonica and Indica hybrid rice, and Hoshiyutaka high-amylose rice, were cultivated in an experimental field of Kyushu University in 2008. Koshikihari high-quality premium rice and Yumetoiro high amylose Indica rice were cultivated in an experimental field of Hokuriku Research Center in Joetsu in 2008. Benisarasa red rice, Natsugumo and Akiyama low-amylose rice, Koshinomenjin high-amylose rice, and Takenari Indica rice, were cultivated at the Niigata Prefectural Agricultural Research Institute in 2008.

Commercial rice cracker and handmade rice cracker samples. Milled grains (7 g) of Hoshiyutaka, Koshikihari, Yumetoiro, Benisarasa, Natsugumo, Akiyama, Koshinomenjin and Takenari Indica rice were baked with a puffing grain machine (Tatibanakikou, Co., Ltd.) at 220 °C for 10 s. The pressures during the steady state was 10.0 MPa. Commercial rice crackers were made by several confectionery companies in Niigata prefecture and were purchased in the local market.

Measurement of the moisture content. Milled rice grains for puffing and the hand-made rice crackers were pulverized with an IFM-100 coffee mill, (Iwatani, Tokyo, Japan), and the moisture content of the flours was measured by an oven-drying method,25 drying 2 g of flour at 135 °C for 1 h as described in the previous reports.7–9 Commercial rice crackers were crushed with a coffee mill, and the moisture content of the broken granules was measured by an oven-drying method, drying 2 g of the flour at 135 °C for 3 h.

Amylose content. The amylose content of the milled rice was measured by the iodine colorimetric method of Juliano.26 Type III potato amylose (Sigma Chemical Co., St. Louis, MO, USA) and waxy rice starch (with the fat and proteins removed from waxy rice) were respectively used as standard amylose and standard amyllopectin for the amylose determination.

Protein content. The nitrogen content was measured by the official AOAC (Kjeldahl) method, and the protein content was then calculated by multiplying the nitrogen-protein conversion coefficient of 5.95.27

Measurement of the pasting properties of the rice flour samples. The pasting properties of the rice flour samples were measured with an RVA Super 4 model rapid-visco-analyzer (New-port Scientific, Warriewood, New South Wales, Australia). As sample, 3.5 g (based on 14% moisture) was added to 25 mL of water. The sample cup was fitted to the rotor of the RVA and heated at 90 °C for 1 min and then heated to 93 °C in 4 min. The sample temperature was held at 93 °C for 7 min, and then cooled from 93 °C to 50 °C in 4 min, before finally being allowed to stand for 3 min at 50 °C. The programmed heating and cooling cycle was followed as outlined by Toyoshima et al.28

Measurement of the physical properties of cooked rice grains. Each rice grain sample (10 g) for hand-made rice crackers was put into a pudding cup, water (16 g) was added, and the sample was soaked for 1 h at 25 °C. Five of these pudding cups (5 cups) were transferred to an RC3 electric rice cooker (Toshiba, Tokyo, Japan) and cooked as described in our previous report.24,29 The physical properties of the cooked rice grains were measured by the high-compression/low-compression method with a My Boy Tensipresser (Taketomo Electric, Co., Tokyo, Japan) under the same conditions as those reported in our previous paper.29

Measurement of the physical properties of the rice crackers. The physical properties of the rice crackers were measured by the one-bite test with the My Boy Tensipresser (Taketomo Electric, Co., Tokyo, Japan) under the following; plunger (13 mm diameter), suacer (80 mm length, 80 mm width), bite speed 2 mm/s, distance, 30 mm, clearance, 3 mm, thickness, 15 mm; base line, 3; load cell, 10kg. Measurements were taken five 5 times and the data were statistically treated by using the software provided with the Tensipresser (Fig. 1), which gave the H1, A1, A2, A3, L1, L2, L3, S1, fracture, inflection, and Max stress of the rice crackers. H shows the compression force of the plunger, L shows the moving distance of the plunger, A shows as the area surrounded by the stress profile and absissa (workload), fracture shows the peak subtracted from the bottom, inflection shows INFI, INF2 and INF3, and Max stress shows the maximum compression load.

Sensory evaluation. The sensory test was carried out by the method reported in our previous paper for wheat/rice bread.60 The handmade puffed rice crackers were subjectively scored by 10 trained taste panelists. Five ranking were used to evaluate the appearance, aroma, hardness, taste and overall liking. Puffed rice crackers for the sensory test were prepared by the above-mentioned method from milled grains of Koshikihari and Hoshiyutaka rice, a puffed rice cracker made from Hoshiyutaka rice being used as a control (3 points). The commercial rice crackers were scored subjectively by the 10 trained taste panelists for very soft (10 points), soft (20 points), a little soft (30 points), neither soft nor hard (40 points), a little hard (50 points), hard (60 points), and very hard (70 points) with the focus on hardness.
A. C, and E, Inflection; F, Max stress; B, First max fracture point; Fracture, peak-bottom; G, Max negative compressive stress point. The physical properties of the rice crackers were measured by the one-bit test with a My Boy Tensipresser (Taketomo Electric, Co., Tokyo, Japan). The following conditions were used; plunger (13 mm diameter), saucer (80 mm length and 80 mm width), bite speed (2 mm/s), distance (30 mm), clearance (3 mm), thickness (15 mm), base line (3), load cell (10 kg).

Table 1. Main Chemical Components and Physical Properties of Milled Rice

<table>
<thead>
<tr>
<th>Moisture</th>
<th>Amylese</th>
<th>Protein</th>
<th>H1</th>
<th>H2</th>
<th>S1</th>
<th>S2</th>
<th>L1</th>
<th>Balance A1</th>
<th>Balance A2</th>
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<td>%</td>
<td>%</td>
<td>%</td>
<td>gw/cm²</td>
<td>gw/cm²</td>
<td>gw/cm²</td>
<td>gw/cm²</td>
<td>mm</td>
<td>A3/A1</td>
<td>A6/A4</td>
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<tr>
<td>Koshihikari</td>
<td>12.5a</td>
<td>0.06</td>
<td>17.6a</td>
<td>0.21</td>
<td>5.5a</td>
<td>0.06</td>
<td>68.3a</td>
<td>16.0</td>
<td>1499.0a</td>
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<tr>
<td>Hoshiyutaka</td>
<td>11.2b</td>
<td>0.10</td>
<td>29.9b</td>
<td>0.15</td>
<td>6.3b</td>
<td>0.10</td>
<td>88.5a</td>
<td>19.0</td>
<td>2093.0b</td>
</tr>
<tr>
<td>Yumetoro</td>
<td>12.3a</td>
<td>0.06</td>
<td>32.0c</td>
<td>0.10</td>
<td>6.9b</td>
<td>0.10</td>
<td>99.3a</td>
<td>19.3</td>
<td>2291.0b</td>
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<td>Takanari</td>
<td>13.3c</td>
<td>0.05</td>
<td>19.0a</td>
<td>1.02</td>
<td>5.5a</td>
<td>0.05</td>
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<td>11.0</td>
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<td>0.39</td>
<td>15.7d</td>
<td>0.24</td>
<td>5.4a</td>
<td>0.05</td>
<td>60.9a</td>
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<td>Koshinomenjiman</td>
<td>13.8c</td>
<td>0.31</td>
<td>28.4b</td>
<td>0.19</td>
<td>5.4a</td>
<td>0.05</td>
<td>82.0a</td>
<td>17.2</td>
<td>2281.3b</td>
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<tr>
<td>Akiogamo</td>
<td>13.4c</td>
<td>0.20</td>
<td>11.0e</td>
<td>0.06</td>
<td>5.5a</td>
<td>0.05</td>
<td>55.1b</td>
<td>11.3</td>
<td>1716.7a</td>
</tr>
<tr>
<td>Natsugumo</td>
<td>13.2c</td>
<td>0.09</td>
<td>7.2f</td>
<td>0.09</td>
<td>6.1b</td>
<td>0.05</td>
<td>54.0b</td>
<td>11.1</td>
<td>1621.3a</td>
</tr>
</tbody>
</table>

Correlation significant at 5% by the method of Tukey. same letter means not significantly different.

Measurement of the fat acidity of the rice crackers. The fat acidity of the rice crackers was measured by the colorimetric method of Ohtsubo et al. Measurement of the fat acidity of the rice crackers (100 mg) was put into a stoppered test tubes (10 mL, Sibata, Science Co., Saitama, Japan), and 6 mL of toluene was added and mixed well to extract the free fatty acid for 30 min at 30 °C. The solution was passed through a no. 2 filter paper (110 mm diameter, Advantec, Tokyo, Japan). One mL of the filtrate solution was put into a different stoppered test tube, and 4 mL of chloroform and 2.5 mL of a copper reagent (90 mL of 1 M triethanolamine 90 mL, 10 mL of 1 N acetic acid, and 100 mL of 0.45% copper nitrate) were added and mixed well. After centrifugation (1500 g, 5 min, 4 °C), this solution was separated into a solvent phase. The copper solution was removed, 3 mL of the chloroform solution was put into a different stoppered test tube, and 0.5 mL of a coloring reagent (0.1% sodium diethyldithiocarbamate in isobutyl alcohol) was added, mixed well and the tube stood for 30 min at 20 °C. The absorbance of the solution was measured at 440 nm with a UV-1600 spectrophotometer (Shimadzu, Kyoto, Japan). A calibration curve was made with linoleic acid, and the amount of free fatty acid was calculated according to this calibration. The fat acidity ratio is expressed as the volume of potassium hydroxide to neutralize the free fatty acid in 100 g of rice flour (dry matter).

Results and Discussion

Moisture content
Rice and processed rice quality is greatly affected by the moisture content; the higher the amount of moisture, the faster the quality of a rice crackers deteriorates. The moisture content of rice and processed rice therefore needs to be kept at a low level. Table 1 shows that Hoshiyutaka, the Japonica and Indica hybrid rice, had a low moisture content (11.2%), while the other rice samples had a moisture content the range of 12.3%–13.8%. The moisture content of the constituent rice was adjusted to about 10% before baking and the moisture content of the rice cracker was kept at about 3%–5% after baking as reported in the previous references.7,9

Apparent amyllose content
Amylose is a non-branchned 1, 4 glucan, which is one of the components of rice starch and greatly affects the quality and gelatinization properties of cooked rice.25,29 Low-amyllose rice generally becomes soft and sticky upon cooking, while high-amyllose rice becomes hard with the grains separated.29 The starch of low-amylose rice is not easily retrograded as Takami et al. have reported.31 The quality of rice crackers is affected by
their amylose content.\textsuperscript{2,29} Table 1 shows that the amylose contents of Yumetoiro (32.0\%), Hoshiyutaka (29.9\%) and Koshinomenjiman (28.4\%) were high, not endowing them with good eating characteristics, but they were suitable for processing rice flour, rice noodles, pilaf and curry rice. Takanari (19.0\%) is characterized as having a medium amylose content, making it suitable for the hard type of rice crackers, dumplings, brown rice tea and rice bread.\textsuperscript{2-5} The red rice, Benisarasa, showed a low amylose content (15.7\%) and, seemed to be suitable for the soft type of rice cracker. It would also be useful for unpolished rice food, unpolished rice porridge and rice snacks, because the red pigment is localized only in the outer layer of the kernel. Koshihikari (17.6\%) showed a low amylose content and has the best eating quality in Japan.\textsuperscript{6,29} Akigumo low-amylose rice (11.0\%) and Natsugumo (7.2\%) are characterized as having an exceptionally low amylose content, their starches are therefore not easily retrogradad and maintain high stickiness well. These two cultivars are expected to be suitable for rice crackers (soft type), box lunches and rice balls.\textsuperscript{2,22} Low-amylose rice was found generally suitable for soft-type rice crackers because it expanded well, while high-amylose rice was suitable for hard-type rice crackers because it did not expand well.\textsuperscript{22} Among the components, increasing the amylose content of the starch decreased the expansion rate of rice crackers as reported by Yamada \textit{et al.}\textsuperscript{23}

**Protein content**

Protein is the second most abundant constituent of milled rice after starch. The amount of protein affects the physical properties of cooked rice grains, the higher the protein content, the harder and less sticky the rice grains become upon boiling.\textsuperscript{2,30} The protein content of \textit{Japonica} milled rice is generally 6.8\%.\textsuperscript{31} Table 1 shows that the protein contents of Koshihikari (5.5\%), Takanari (5.5\%), Benisarasa (5.4\%), Koshinomenjiman (5.4\%) and Akigumo (5.5\%) were low, while Yumetoiro (6.9\%), Hoshiyutaka (6.3\%) and Natsugumo (6.1\%) had intermediate protein contents.

**Physical properties of cooked rice grains**

The measured physical properties of the cooked rice grains by low-compression (25\%) and high-compression (90\%) methods\textsuperscript{24,26} with the Tensipresser are shown in Table 1. A clear difference was detected by the LC (low-compression) test for H1 (surface hardness). There was a difference in H1 between Natsugumo (54.0 gw/cm\textsuperscript{2}) and Akigumo (55.1 gw/cm\textsuperscript{2}) as cultivars with very low amylose content and Koshihikari (68.3 gw/cm\textsuperscript{2}) and Benisarasa (60.9 gw/cm\textsuperscript{2}) with low amylose content. There was also a difference in H1 among Yumetoiro (99.3 gw/cm\textsuperscript{2}), Hoshiyutaka (88.5 gw/cm\textsuperscript{2}) and Koshinomenjiman (82.0 gw/cm\textsuperscript{2}) as cultivars with high amylose content, while Takanari had a medium value (62.4 gw/cm\textsuperscript{2}), being the soft type of \textit{Indica} rice. Cooked rice grains with higher amylose contents generally have a harder texture.\textsuperscript{29} The surface stickiness (S1) data show higher values for Akigumo (10.8 gw/cm\textsuperscript{2}) and Natsugumo (10.5 gw/cm\textsuperscript{2}) than Koshihikari (7.1 gw/cm\textsuperscript{2}) and Benisarasa (7.4 gw/cm\textsuperscript{2}). Yumetoiro (0.9 gw/cm\textsuperscript{2}), a high-amylose rice, had the lowest value, while Hoshiyutaka (3.0 gw/cm\textsuperscript{2}) and Koshinomenjiman (4.3 gw/cm\textsuperscript{2}) had lower values than Takanari (4.6 gw/cm\textsuperscript{2}). In contrast, Koshihikari, rice with good eating quality showed the highest value for overall stickiness (365.2 gw/cm\textsuperscript{2}), S2) and the lowest value for overall hardness (1499.0 gw/cm\textsuperscript{2}, H2), while Yumetoiro, a high-amylose cultivar, showed the lowest value for overall stickiness (0.9 gw/cm\textsuperscript{2}, S2) and the highest value for overall hardness (2291.0 gw/cm\textsuperscript{2}, H2). The values of Balance A1 (the ratio of work for adhesiveness to work for hardness of the surface layer of the cooked rice grains, A3/A1) and Balance A2 (the ratio of work for adhesiveness to work for hardness of the overall layer of the cooked rice grains, A6/A4) are important indices in evaluating the palatability of rice.\textsuperscript{30} For balance A (A3/A1), Akigumo (0.60) and Natsugumo (0.64) showed higher values than Koshihikari (0.17) and Benisarasa (0.41), while Yumetoiro (0.04) showed lower values than Hoshiyutaka (0.07), Takanari (0.20) and Koshinomenjiman (0.19). Among these textural analyses, the degrees of change in the hardness and stickiness obtained by the low-compression test could well express the degree of stalting of cooked rice, and Akigumo and Natsugumo, low-amylose cultivars, were found to be stale-resistant rice cultivars as Takami \textit{et al.} have previously reported for the staling characteristics of the cooked low-amylose rice cultivar, Snowpearl.\textsuperscript{31} The palatability and acceptability of rice are greatly affected by the physical properties of hardness and stickiness. Koshihikari, Benisarasa, Akigumo and Natsugumo, as low-amylose cultivars, showed good eating qualities due to their physical properties of low hardness and high stickiness, while Yumetoiro, Hoshiyutaka and Koshinomenjiman with high-amylose content, exhibited a hard texture with high hardness and low stickiness. Takanari, a soft type of \textit{Indica} cultivar, showed a soft texture after cooking, for example, low surface hardness and medium overall stickiness.

**Pasting properties of rice flour samples from the various cultivars**

Since the pasting properties also influence rice eating quality, it is meaningful to conduct a gelatinization test for a quality assay of rice crackers. Break down indicates the ease with which the starch granules were disintegrated.\textsuperscript{11} High-amylose cultivars had a higher final viscosity than low-amylose cultivars, the final viscosity being related to the degree of starch retrogradation upon cooling.\textsuperscript{23} The expansion rate of rice crackers upon roasting has shown a highly negative correlation with the ratio of Final viscosity to Max. viscosity and the ratio of Consistency to Break down on an amylogram.\textsuperscript{23} Table 2 shows that consistency value for Koshinomenjiman, a high-amylose cultivar, was very low, and those for Akigumo (78.9 RVU) and Natsugumo (64.6 RVU), both low-amylose cultivars, were low, while those for Koshihikari (144.2 RVU), Takanari (120.8 RVU) and Benisarasa (118.2 RVU) were medium values. On the other hand, Yumetoiro (293.8 RVU) and Hoshiyutaka (232.6 RVU), high-amylose cultivars, indicated high values. The ratio of consistency to breakdown (consistency/breakdown) of Yumetoiro (1.8) was very high, that of Hoshiyutaka (1.4) was high, while those of Koshihikari (0.5), Benisarasa (0.5), Takanari (0.5) and Koshinomenjiman...
Natsugumo are also suitable for box lunches, rice balls for rice flour, rice noodles, the index of starch Koshihikari (0.7), Benisarasa (0.7) and Takanari (0.7).

Balance A2 0.45

S2 0.49

Akigumo 399.9b 3.1 113.5d 1.8 286.4a 3.0 192.5e 2.1 872.5c 3.1 789.8d 1.3 67.9e 3.6 0.3a 0.4 0.5a 0.7

Natsugumo 392.1b 3.3 93.9d 1.4 298.7a 2.2 157.9f 0.8 234.2c 2.6 64.6d 0.6 68.0b 4.6 0.2a 0.3 0.4a 0.2

Correlation significant at 5% by the method of Tukey. Same letter are not significantly different.

Table 3. Correlation between Chemical Components and Physical Parameters of Milled Rice Samples

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<th>Moisture</th>
<th>Amylose</th>
<th>Protein</th>
<th>H1</th>
<th>H2</th>
<th>S1</th>
<th>S2</th>
<th>L3</th>
<th>Bal.A1</th>
<th>Bal.A2</th>
<th>Max vis</th>
<th>Min vis</th>
<th>Break down</th>
<th>Final vis</th>
<th>Setback</th>
<th>Consistency</th>
<th>Pasting temp</th>
<th>Cons/ B.D</th>
<th>Final vis/ Max vis</th>
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<tbody>
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Correlation is significant * or ** at 5% or 1%, respectively by the method of t-test.

(0.5) were low, and those of Akigumo (0.3) and Natsugumo (0.2) were very low. The ratios of final viscosity to maximum viscosity (Final vis/Max vis) for Yumetoiro (1.3) and Hoshiyutaka (1.2) were very high, for Koshihikari (0.8) was high, while those for Koshihikari (0.7), Benisarasa (0.7) and Takanari (0.7) were medium values, and those for Akigumo (0.5) and Natsugumo (0.4) were very low. As a result, Koshinomenjiman, a high-amylose cultivar, is suitable for rice flour, rice noodles, the index of starch retrogradation indicating a low value. Akigumo and Natsugumo, both low-amylose cultivars, are suitable for rice crackers (the soft type) because their expansion rate index had a high value; moreover, Akigumo and Natsugumo are also suitable for box lunches, rice balls and rice blending, because their indices of low-amylose starch retrogradation were low.31) Yumetoiro and Hoshiyutaka are suitable for the hard-type of rice cracker because their expansion rate indices had low values, and they tended to expand less than the other rice cultivars.

Correlation among the physicochemical and pasting properties of the rice samples

Significant correlations among the physicochemical properties are shown in Table 3. The apparent amylose contents showed positive correlations with the ratio of final viscosity to maximum viscosity (r = 0.93), setback (r = 0.99), and with ratio of consistency/break-down (r = 0.81), and negative correlations with S1 (r = 0.95), S2 (r = 0.88), balance A1 (r = 0.90) and balance A2 (r = 0.94) at the level of 1%. Since the cooked high-amylose rice samples were hard and tough, it seemed that they could not be suitable as a material for soft-type rice crackers, due to their higher ratio of final viscosity to maximum viscosity and the higher ratio of consistency to break down.

The protein content was positively correlated with Final vis (r = 0.74), consistency (r = 0.79), with the ratio of consistency/breakdown (r = 0.82), and negatively correlated with S1 (r = 0.95), S2 (r = 0.88), balance A1 (r = 0.90) and balance A2 (r = 0.94) at the level of 1%. The surface hardness (H1) could distinguish the difference in protein content among rice samples of the same cultivar.33) The value for H1 (surface hardness) was found to have a positive correlation with the protein content.

The results of this study show, H1 (surface hardness) to be positively correlated with the ratio of consistency/break down (r = 0.89), the ratio of Final vis/Max vis (r = 0.95), and with setback (r = 0.97) at the level of 1%, and negatively correlated with S1 (r = 0.91), S2 (r = 0.94), balance A1 (r = 0.85), balance A2 (r = -0.86) and break down (r = -0.84) at the level of 1%.
The surface hardness (H1) had a higher negative correlation by RVA with the factor for the expansion rate of rice crackers similar to overall hardness H2. The surface stickiness (S1) showed positive correlations with S2 (r = 0.87), balance A1 (r = 0.93) and balance A2 (r = 0.96) at the level of 1%, and negative correlations with setback (r = −0.93), ratio of consistency/breakdown (r = −0.83) and ratio of Final vis/Max vis (r = −0.92) at the level of 1%. The surface stickiness (S1) had a higher positive correlation by RVA with the factor for the expansion rate of rice crackers, similar to the overall stickiness (S2). The ratio of stickiness/hardness (the balance degree) is an important index in evaluating the palatability of rice in Japan. Balance A1 (the surface ratio of stickiness/hardness) showed a positive correlation with balance A2 (r = 0.95) at the level of 1%, and a negative correlation with setback (r = −0.84) and the ratio of Final vis/Max vis (r = −0.86) at the level of 1%, similar to the overall ratio of stickiness/hardness (balance A2).

As a result, Min vis, which had a high correlation with ratio of Final vis/Max vis and with the ratio of consistency/breakdown, was a more useful indicator to distinguish the expansion rate of rice crackers than the Max vis value. Consistency was positively correlated with the ratio of Final vis/Max vis (r = 0.87) and with the ratio of consistency/breakdown (r = 0.96) at the level of 1%. The ratio of consistency/breakdown was positively correlated with the ratio of Final vis/Max vis (r = 0.96) at the level of 1%.

We therefore propose the ratio of Final vis/Max vis, which had high correlation with the ratio of consistency/breakdown, amylose content, surface hardness (H1), final viscosity and setback as a very useful indicator to distinguish the expansion rate of rice crackers.

Physical properties of the rice crackers

Young’s modulus can be experimentally determined from the slope of the stress-strain curve created during a compression test conducted on a sample of material. Young’s modulus for anisotropic materials, may have different values depending on the direction of the applied force with respect to the material’s structure. As shown in Table 4, H1 showed positive correlation with A2 (r = 0.97) at the level of 1%. L2 showed positive correlation with A2 (r = 0.84) and Max stress (r = 0.85) at the level of 1%. Max stress, one of the factors related the quality and characteristics of rice crackers, showed positive correlation with H1 (r = 0.88) and A2 (r = 0.94) at the level of 1%. The profile of the physical properties of puffed rice crackers is shown in Fig. 2A. As the results, Max stress values of the high-amylose rice cultivars were higher than those of low amylose rice.

Figure 3 shows the indices of H1, A2 and Max stress for Koshinomenjiman to be higher than those for Yumetoiro and Hoshiyutaka, while the fracture value was lower than that for Yumetoiro and Hoshiyutaka. The amylose contents of Yumetoiro (32.0%) and Hoshiyutaka (29.9%) and Koshinomenjiman (28.4%) were about same. But, overall stickiness (S2) of Koshinomenjiman (201.4 gw/cm²) was higher than that of

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Correlation is significant * at 5% or ** at 1% respectively by t-test.
for Yumetoiro (9.1 gw/cm²) and Hoshiyutaka (141.1 gw/cm²) as shown in Table 1. And the value for consistency, which is related to the degree of starch retrogradation, of Koshinomenjiman (49.7 RVU) was lower than the values for Yumetoiro (293.8 RVU) and Hoshiyutaka (232.6 RVU) while the ratio of consistency/breakdown, which is related to the low expansion rate of rice crackers, was positively correlated with the amylose content ($r = 0.87$), protein content ($r = 0.92$), Min vis ($r = 0.81$), Final vis ($r = 0.86$), setback ($r = 0.89$), consistency ($r = 0.84$), ratio of consistency/breakdown ($r = 0.94$) and ratio of Final vis/Max vis ($r = 0.95$) at the level of 1%. As suitable indices for evaluating the rice cracker texture, parameters for cooked rice palatability, such as H1 and S2, chemical component of rice grain (amylose and pasting properties) were selected among all the measured parameters.

Calibration model to estimate fracture of the rice crackers is shown in Fig. 4. We developed a multiple-regression equation for fracture of the puffed rice crackers as a function of five physical or chemical parameters of the rice flour samples and grains. The formula for estimating fracture was as follows: $2.66 \times H1 - 0.71 \times S2 - 10.19 \times amylose content + 27.30 \times consistency/breakdown + 743.75 \times Final vis/Max vis + 136.28$. The multiple regression coefficient was found to be 0.93.
The multiple-regression coefficient was found to be 0.93.

Fig. 5. Calibration for the Amylose Content of Material Rice Based on a Multiple-Regression Analysis, Using Several Physical Parameters as Independent Variables.

1. Koshihikari; 2, Hoshiyutaka; 3, Yumetoiro; 4, Takanari; 5, Benisara; 6, Koshinomenjiman; 7, Akigumo; 8, Natsugumo.

Observation; ———, Theoretical value. Fracture = 2.66 × H1 − 0.71 × S2 − 10.19 × amylose content + 27.30 × consistency/breakdown + 743.75 × Final vis/Max vis + 136.28. The multiple regression coefficient was found to be 0.9285. As suitable indices for the multiple-regression analysis as textural parameters related to the palatability of cooked rice grains to estimate the fracture (one of the important textural parameters for rice crackers), H1 (surface hardness) and S2 (overall stickiness), the amylose contents (one of the main chemical components of rice grains), and Final vis/Max vis and consistency/breakdown (parameters for the pasting properties of the rice flour samples) were selected from among the parameters analyzed in each test.

We could estimate the fracture characteristics of a rice cracker, which are closely related to the palatability of the rice cracker based on the physicochemical properties of the rice material and we could as well estimate the amylose content, which is closely related to the expansion and retrogradation of a rice cracker based on the product’s physical properties. However, this estimate would only be valid when the manufacturing conditions and storage period are same, because these conditions affect the physical properties of a rice cracker.

Relationship between physical properties and fat acidity of rice crackers during storage

The physical properties of six kinds of commercial rice cracker were measured by the novel method of a one-bite test with a Tensipresser as shown in Fig. 6. Rice cracker A was the hard type rice crackers, B, C and D were the soft type, and rice crackers E and F were the rather hard type rice. Rice crackers C (H1) and D (H1) were significantly different with rice crackers E (H1) and F (H1) at the respective levels of 1% and 5%. Rice crackers A (A1), B (A1), C (A1), D (A1), and F (A1), and rice cracker E (A1) were significantly different at the level of 1%. H1 showed positive correlation with Max stress (r = 0.96) at the level of 1% and with A1 (r = 0.83) at the level of 5%.

To summarize, rice crackers E and F were harder than rice crackers C and D. Rice cracker A was the hard type, showing that the degree of expansion of air bubbles was associated with the physical properties of the rice crackers. The physical properties of the soft type of rice cracker could be evaluated more easily than the hard type by our novel method of the one-bite test with a Tensipresser. Such textural parameters, as Max stress, A1, and H1, are proposed to be suitable for classifying rice crackers according to their hardness. These parameters are simple and useful, because only physical measurement is necessary to evaluate or classify commercial rice crackers.

The physical properties of six kinds of commercial rice crackers after storage were also measured. Fat acidity has been reported to be one of the important indices for the quality deterioration of rice, so we tried to use it to check the quality deterioration of rice crackers during storage. We adopted the colorimetric method for measuring the fat acidity, the results for the commercial rice crackers before and after storage (for 20 d at 35 °C, packed in plastic bags) being shown in Fig. 7. The fresh rice crackers showed less fat acidity than after storage, when it increased by 1.5–4.0 times. Commercial rice cracker D showed a particularly high increase of fat acidity. The variation of fat acidity with the physical properties of commercial rice crackers during storage is shown in Fig. 8. The values of the physical properties increased between 1.2 times–9.1 times during the storage of rice crackers. A2 of the physical parameters showed a particularly high rate of increase. The increase of H1 and increase of Max stress were significantly correlated at the level of 1%, the increase of fat acidity and H1 were significantly correlated at the level of 5%. As shown in Fig. 2B, profile-a shows fresh commercial rice cracker and profile-b shows rice cracker whose expiration date had
Fig. 6. Physical Properties of Commercial Rice Crackers Measured by One-Bite Method Using a Tensipresser.
A, Rice cracker A; B, Rice cracker B; C, Rice cracker C; D, Rice cracker D; E, Rice cracker E; F, Rice cracker F. Correlation is significant at 5% respectively by the method of Tukey. Same letter means not significantly different. Rice cracker E and F were harder than rice cracker C and D. The soft type rice crackers were more suitable than hard type ones for the measurement of physical properties by the novel method of one bite test with a Tensipresser.

Fig. 7. Change in Fat Acidities of Various Commercial Rice Crackers Before and After Storage.
Fresh rice crackers; Stale rice crackers (stored at 35 °C for 20 d). a, Rice cracker A; b, Rice cracker B; c, Rice cracker C; d, Rice cracker D; e, Rice cracker E; f, Rice cracker F. Same letter means not significantly different. Values are the average of triplicate measurements. The bar showed standard deviation. After the storage, fat acidities of rice crackers increased 1.5 times–4.0 times those of fresh crackers. Commercial rice cracker D showed particularly high ratio of increase.

Degree of quality deterioration of the rice crackers by the physical method of the one-bite test with a Tensipresser. The fat acidity could also be a useful chemical index of quality deterioration during the storage of rice crackers.

Sensory evaluation
The objective of this study was to investigate the various methods for measuring the physical and chemical properties of rice crackers and to propose method for evaluating the quality of rice crackers in accordance with the sensory evaluation.

Several attempts have been made to classify the hardness of rice crackers based on their mechanical properties and a sensory evaluation. However, such reports have revealed that the mechanical properties of rice crackers did not completely match the results of the sensory evaluation. Our sensory test shown in Fig. 9 indicates that hardness by the sensory analysis and H1 (from the physical properties) and Max stress (from the physical properties) were significantly correlated at the level of 1%.

The results of the sensory evaluation of six kinds of commercial rice cracker given in Fig. 10 show a significant correlation between the sensory analysis, and the values for physical parameters of commercial rice crackers. The hardness by the sensory analysis, and the values for H1 (physical properties), Max stress (physical properties) and A1 (physical properties) were significantly correlated at the level of 1%. It was found that H1 and Max stress, by the physical measurements were useful parameters to classify rice crackers according to their hardness, because these factors significantly affected the hardness of rice crackers by the sensory test. It seems relevant that these physical parameters showed significant correlation for both hand-made rice crackers and rice crackers. One of the reasons for this high
Conclusions

The degree of swelling is one of the criteria for high quality rice crackers, and while it varies, depending upon the rice cultivar, genealogy, and manufacturing conditions, the cause-and-effect relationship has not been clearly defined.28,34,35

The objective of this present study is to examine several advanced methods for measuring the physical properties of rice crackers and to propose a novel method for evaluating rice crackers based on the hardness in the sensory evaluation.

The suitability for processing of eight kinds of rice variety was characterized according to the results of physicochemical quality assays. The novel one-bite test with a Tensipresser was proposed for evaluating rice crackers focusing on their hardness.

Puffed rice crackers were prepared, and the relationship between the physicochemical properties of the rice grains used and the quality of the resulting products was investigated.

It was found possible to estimate the physical properties of rice crackers by using a multiple-regression analysis based on the chemical components, pasting properties and physical properties of the rice used. A formula for estimating the amylase contents of the rice samples was developed by using the results of physicochemical measurements of the rice crackers.

We assayed the quality of commercial rice crackers and examined their deterioration during storage by measuring the physicochemical properties. The hardness and fat acidity of the crackers increased markedly during storage for 20 d at 35 °C.

The novel method of the one-bite test with a Tensipresser was useful for a quality assay of the rice crackers, and made it possible to evaluate the quality deterioration of the rice crackers during storage.

Acknowledgment

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