Properties and Gel Characteristics of Flour and Starch Obtained from Newly Developed Rice Cultivars*

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Five newly developed rice (aromatic Sari-queen, low amylose Dohoku 43, high amylose Hoshiyutaka, giant grain Ochikara, and high yield Habataki rice) were studied. To determine the properties of the flour and starches of the newly developed rices, swelling power and solubility, photopastegraphy, viscosography and starch gel texture were examined. The stability during storage at a low temperature was determined by measuring the water syneresis ratio and the whiteness of the starch gel. The swelling power of rice starch at 90°C ranged from 17 to 26. Hoshiyutaka had the lowest, and Ochikara the highest values. Dohoku 43 and Nipponbare were difficult to swell. Sari-queen showed a high maximum viscosity, a high viscosity in the cooling step and a large breakdown, i.e., low heat stability. Hoshiyutaka, which showed a viscosity curve similar to that of the corn starch, can be used in foods by taking advantage of its gelling properties. Hoshiyutaka and Sari-queen were high in firmness of starch gel, and the firmness was increased when stored at a low temperature. The Nipponbare gel was soft, and the Dohoku 43 gel, intermediate in softness. In this third study, the gelatinization and retrogradation properties, gel texture and stability of the flour and starches of newly developed rice were determined. Forth coming studies will look at how the varied properties of the flour can be used for many kinds of cooking and processing, including couscous and traditional Japanese sweets and cakes (Dango and Uiro).

(Received July 16, 1997; Accepted in revised form December 15, 1997)

Keywords: newly developed rice cultivar, swelling power-solubility, freeze-thaw stability, syneresis, Hanter whiteness.

INTRODUCTION

The development of rice cultivars with new characteristics cannot be expected to yield either an improvement in the species or remarkable variation in Japonica due to its narrow genetic characteristics (Saio 1990). Thus, attempts have been made to apply various characteristics of foreign rice cultivars to Japanese rice to create genetic resources with characteristics largely different from those of conventional rice cultivars. Consequently, various new cultivars have been developed (Nakagawara 1991), including giant-grain rice, slender-grain rice, rice varying in amylose content, giant-embryo rice, protein-rich rice, colored rice, and aromatic rice (Ishitani 1993; Takahashi 1993).

Part 1 of this study clarified the factors responsible for the difference in taste between three rice varieties by examining their cooking properties as steamed white rice and as Sakura-meshi. In Part 2, using established rice cultivars with differing tastes and newly developed cultivars as samples, the relationship between the texture and starch structure of rice was studied by determining the amylose content and chain length distribution of amyllopectin by the gel filtration method, and the average unit chain length of amyllopectin by both the modified Smith degradation and an enzymatic method. The results indicate that the rice taste was closely related to the rice starch structure.

In this third study, the properties and gel characteristics of rice flour and rice starch were examined to provide fundamental information about newly developed rice cultivars.
MATERIALS AND METHODS

Materials
1. Rice samples
   Six varieties of rices, involving five newly developed rice cultivars produced in 1990 and Nipponbare produced in Shiga as the standard, were used (Table 1). The rice samples were Sari-queen (long-grain basmati (aromatic) rice, National Agriculture Research Center); Dohoku 43 (low-amylose rice, Kamikawa Agricultural Experimental Station); Habataki (high-yield rice, Hokuriku Agricultural Experimental Station); Ochikara (giant-grain rice, Hokuriku Agricultural Experimental Station); and Hoshiyutaka (indica-japonica hybrid rice, Chugoku Agricultural Experimental Station). Each rice sample had been polished to a milling yield of 92%.

2. Preparation of rice flour and rice starch samples
   Each rice flour was prepared from rice grains washed with water and dried at room temperature, and was obtained by grinding in a Brabender test mill (Quadrumat-Muhle Nr. 364, Brabender Co.) and then by passing through an 80-mesh sieve. Each rice starch was prepared by immersing the rice in a diluted alkali solution according to the procedure of Yamamoto et al. (1973). After soaking the rice flour in the alkali solution 3 times, distilled water was added, and the rice flour was repeatedly washed with water until pH 7 was indicated (about 10 times). It was then dried at room temperature to give the starch sample.

Measurement methods
1. Moisture content
   The moisture contents of each rice flour and rice starch were measured by the atmospheric pressure drying method (American Association of Cereal Chemists 1983) (drying at 135°C for 2 h).

2. Protein content
   The protein contents of each rice flour and rice starch were determined by the micro-Kjeldahl method (Nagahara et al. 1986), using a nitrogen conversion constant of 0.59.

3. Starch granule size distribution
   The starch granule size distribution of each sample was determined by using a Coulter counter multisizer (Nikkaki).

4. Swelling power and solubility
   In accordance with the method of Kainuma et al. (1967), 0.5 g dry weight (dw) of a potato starch sample was used, while the other samples were 1.0 g. After heating in a water bath, which was regulated to a temperature of 60, 70, 80 or 90°C while stirring, each sample was centrifuged at 3,000 rpm for 30 min. The supernatant was decanted and the precipitate was weighed. The volume of the supernatant was measured, and the amount of dissolved starch was determined by the phenol-sulfonic acid method (Dobois et al. 1956).

5. Photopastegraphy
   Measurements were taken with a photopastegraph (Hirama Rika Kenkyusho) according to the method of Kainuma et al. (1968). The concentration of each sample was up to 0.2%, while the concentration of the potato starch was adjusted to 0.3%. The temperature was elevated from 25 to 98°C at a rate of 2°C/min, and the absorbance at 372 nm was measured. Also measured were the effects of adding table salt (NaCl), sugar, rice wine, and vinegar to the rice starch samples.

6. Viscography
   The viscosity of rice flour and rice starch was determined with a Brabender viscohraph (model V56E, Brabender Co.), the sample concentration being adjusted to 7.5% for rice starch (dw), or 8.0% for rice flour (dw). Measurements were taken by the conventional method (Tipples 1980) by maintaining the temperature at 95°C for 10 min and then cooling to 25°C.

7. Texture of starch gels and rice flour pastes
   A Tensipresser (TTP-50-BX, Taketomo Denki) was used to measure the texture. By using a cylindrical plunger of 10 mm in diameter, measurements were taken at a compression ratio of 90%. Seven point five percent starch pastes and 8.0% rice flour pastes produced for the viscoigraphy measurements were

Table 1. Suppliers and characteristics of the rice grains

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Supplier</th>
<th>Characteristic</th>
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<tbody>
<tr>
<td>Nipponbare</td>
<td>Shiga Prefecture</td>
<td>Standard</td>
</tr>
<tr>
<td>Sari-queen</td>
<td>National Agriculture Research Center</td>
<td>Aromatic grain</td>
</tr>
<tr>
<td>Dohoku 43</td>
<td>Kamikawa Agricultural Experiment Station</td>
<td>Low amylose</td>
</tr>
<tr>
<td>Habataki</td>
<td>Hokuriku Agricultural Experiment Station</td>
<td>Very high yield</td>
</tr>
<tr>
<td>Ochikara</td>
<td>Hokuriku Agricultural Experiment Station</td>
<td>Large grain</td>
</tr>
<tr>
<td>Hoshiyutaka</td>
<td>Chugoku Agricultural Experiment Station</td>
<td>High amylose</td>
</tr>
</tbody>
</table>
used as samples, while pastes maintained at 95°C for 5 min were used as starch gel samples. Each paste thus obtained was immediately poured into a Petri dish (24 mm in diameter and 6 mm in depth) and stored at 5°C for 1, 3 or 7 days prior to the measurement (Takahashi 1991).

8. Freeze-thaw stability of starch gels

Similar to the measurement of texture by viscosimetry, a paste was prepared by adjusting the starch concentration to 7.5% and maintaining it at 95°C for 5 min for use as the gel sample. A 20 g portion of the sample was immediately put into a plastic container (53 mm in diameter and 20 mm in depth), sealed with a paraffin film and cooled to room temperature in a polyethylene bag with a zipper. The freeze-thaw stability was measured after conducting 1, 4, 7 or 10 constant freezing and thawing cycles (−20°C for about 20 h; room temperature for 4 h) and then measuring the amount of the water syneresis from the gel by the vacuum filtration method (Takahashi and Seib 1988).

9. Whiteness of starch gels

Hunter’s whiteness was determined by using a color difference meter (model Z-1001 DP, Nippon Den-shoku Kogyo) based on a standard white board. The same samples as those used for the gel texture measurements were used. Each sample was poured into a container for the whiteness measurement, sealed and then stored at 5°C for 1, 3, 5, 7 or 10 days prior to determining the Hunter’s whiteness (Takahashi et al. 1993).

RESULTS AND DISCUSSION

Starch granule size distribution

The average starch granule size was in the range of 5.4 to 6.2 µm. Nipponbare used as the standard showed a relatively small granule size of 5.5 µm, while Habataki (high yield) and Ochikara (giant grain) showed large granule sizes of 6.2 µm and 6.1 µm, respectively.

Protein and moisture contents

The protein and moisture contents of the rice flour and rice starch samples are shown in Table 2. The protein content of the rice flour was from 5.4 to 8.5%. Sari-queen (long-grain, aromatic rice) had the highest protein content, while Hoshiyutaka (high amylose content) had the lowest among the samples. Nipponbare and the three other varieties had a similar intermediate protein content. The protein content of rice starch samples ranged from 0.08 to 0.12%, but Hoshiyutaka had a protein content of 0.26%, which is about twice as high as the other starches. Hoshiyutaka thus had a low protein content in the flour but a high protein content in the starch. The moisture contents of the rice flour and rice starch samples ranged from 11 to 15%.

Swelling power and solubility

Figure 1 shows the swelling power and solubility of each rice starch. Nipponbare had low swelling power at 60°C but a marked increase in swelling power with increasing temperature. Dohoku 43 (low amylose content) had high swelling power at 60°C, but this slowly increased with increasing temperature to 80°C. Dohoku 43 showed the lowest solubility of all the samples, indicating that this starch was difficult to swell and dissolve. Hoshiyutaka containing a relatively large amount of amyllose was difficult to swell but had high solubility, while Ochikara showed high swelling power at 90°C.
Photopastegraphy

Table 3 shows the degree of light transmission of each starch determined by photopastegraphy. Nipponbare had a high light transmission-rise onset temperature of 60.5 °C, while Hoshiyutaka had a low onset temperature and a low degree of light transmission at 98°C. Habataki and Ochikara each showed a large increase in the degree of light transmission with increasing temperature, and the highest degree of light transmission at 98°C.

The effect of adding 1% table salt (NaCl) or 30% sugar was to increase the onset temperature by 6-10 °C. However the addition of rice wine or vinegar did not show such a change. Transmittance at 98°C was high in the sample with 30% sugar added, and low in the sample with 1% table salt added.

Viscography

Figure 2 shows viscograms of the rice starch and rice flour samples. The rice starch viscograms (Takahashi 1993) indicate that Sari-queen was high in maximum viscosity and extensive in breakdown, and tended toward a high viscosity during the cooling process. Hoshiyutaka showed a low maximum viscosity, small breakdown and tended to high viscosity during the cooling process. The viscogram of Hoshiyutaka was similar to the curve for corn starch.

Compared with the rice starch samples, the maximum viscosity of the rice flour samples occurred at a higher temperature, although the maximum viscosity was lower by about 200 B.U. The Hoshiyutaka rice flour had a low maximum viscosity and small breakdown, similar to its rice starch. This high heat stability would make it suitable as a rice flour gel.

Textures of starch gels and rice flour pastes

1. Starch gels

As Table 4 shows, Hoshiyutaka formed a firm gel and showed a large increase in firmness with increasing storage time (days), while Nipponbare formed a soft gel. When cooled from 95 to 25°C, each starch gel decreased in firmness, with Hoshiyutaka showing a remarkable decrease in firmness. Stirring in the cooling stage of viscography extensively breaks down starch granules so as to inhibit the formation of a gel.

Sari-queen had high adhesiveness, while Ochikara had low adhesiveness. The adhesiveness of Hoshiyutaka was similar to that of Nipponbare. As the storage time (days) was prolonged, Dohoku 43 and Ochikara increased their adhesiveness, while Hoshi-

Table 3. Effects of adding salt and sugar on the photopastegram of each rice starch

<table>
<thead>
<tr>
<th>Sample</th>
<th>Transmittance-rise onset temperature (°C)</th>
<th>Transmittance at 98°C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No addition</td>
<td>Salt 1%</td>
</tr>
<tr>
<td>Nipponbare</td>
<td>60.5</td>
<td>66.8</td>
</tr>
<tr>
<td>Sari-queen</td>
<td>58.0</td>
<td>62.5</td>
</tr>
<tr>
<td>Dohoku 43</td>
<td>56.0</td>
<td>59.0</td>
</tr>
<tr>
<td>Habataki</td>
<td>58.0</td>
<td>66.0</td>
</tr>
<tr>
<td>Ochikara</td>
<td>57.0</td>
<td>66.5</td>
</tr>
<tr>
<td>Hoshiyutaka</td>
<td>55.0</td>
<td>61.0</td>
</tr>
</tbody>
</table>
yutaka showed a decrease. The Hoshiyutaka gel cooled to 25°C while continuously stirring showed high adhesiveness. Continuous stirring inhibited gelling to give a sticky gel with poor shape retention. The cohesiveness was decreased when stored at a low temperature. Although Hoshiyutaka had high cohesiveness, it was reduced to the lowest level at 25°C. Therefore, Hoshiyutaka suffered from a large reduction in the internal binding force due to stirring during the cooling process.

2. Rice flour pastes

The texture of each rice flour paste shown in Fig. 3 indicates that Hoshiyutaka had high firmness and adhesiveness, while Ochikara (giant-grain rice) had low adhesiveness (about 1/5 of that of Hoshiyutaka).

Freeze-thaw stability of starch gels

Each starch gel was repeatedly frozen and thawed, and the amount of water syneresis was determined. It was found that Dohoku 43 with a low amylose content had little water syneresis after 1 cycle and that Hoshiyutaka (high-amylose rice) and Ochikara (giant-grain rice) underwent serious aging due to freezing. Nipponbare, Sari-queen, Dohoku 43 and Habataki each showed a remarkable increase in the water syneresis ratio after repeated freezing and thawing (Fig. 4).

Whiteness of starch gels

The Hunter whiteness of starch gels has been reported previously (Takahashi 1993). The Hoshiyutaka sample immediately after preparation had high whiteness. After storing at 5°C, a large variation in whiteness was observed among the samples. For instance, Sari-queen had low whiteness and high transparency. On the other hand, Hoshiyutaka and Ochikara showed a large increase in whiteness with

<table>
<thead>
<tr>
<th>Sample</th>
<th>1 day</th>
<th>3 days</th>
<th>7 days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating*</td>
<td>Cooling**</td>
<td>Heating</td>
</tr>
<tr>
<td>Nipponbare</td>
<td>16.6</td>
<td>14.1</td>
<td>25.0</td>
</tr>
<tr>
<td>Adh.</td>
<td>4.2</td>
<td>5.7</td>
<td>4.6</td>
</tr>
<tr>
<td>Sari-queen</td>
<td>57.0</td>
<td>35.2</td>
<td>62.1</td>
</tr>
<tr>
<td>Adh.</td>
<td>7.7</td>
<td>6.0</td>
<td>7.6</td>
</tr>
<tr>
<td>Dohoku 43</td>
<td>32.0</td>
<td>21.1</td>
<td>35.8</td>
</tr>
<tr>
<td>Adh.</td>
<td>4.6</td>
<td>5.2</td>
<td>5.7</td>
</tr>
<tr>
<td>Habataki</td>
<td>32.0</td>
<td>30.7</td>
<td>38.4</td>
</tr>
<tr>
<td>Adh.</td>
<td>5.4</td>
<td>6.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Ochikara</td>
<td>29.4</td>
<td>27.5</td>
<td>31.4</td>
</tr>
<tr>
<td>Adh.</td>
<td>2.5</td>
<td>3.7</td>
<td>3.4</td>
</tr>
<tr>
<td>Hoshiyutaka</td>
<td>73.0</td>
<td>48.0</td>
<td>103.0</td>
</tr>
<tr>
<td>Adh.</td>
<td>4.3</td>
<td>14.4</td>
<td>3.7</td>
</tr>
</tbody>
</table>

* Heating, 25°C→95°C, maintained for 5 min at 95°C. ** Cooling, 25°C→95°C, maintained for 10 min at 95°C→25°C.

Firmness and adhesiveness of 7.5% starch gels determined by a Tensipresser

Fig. 3. Firmness and adhesiveness of rice flour paste as measured by tensipresser

Table 4. Firmness and adhesiveness of 7.5% starch gels determined by a Tensipresser
time, indicating that these starch samples underwent serious aging when stored at a low temperature. These data agree with the measurements of the water syneresis ratio. Hoshiyutaka showed a low degree of light transmission at 98 °C photopastegraphy, low transparency of the starch paste during heating, and low transparency of the gel stored at a low temperature. The low level of whiteness and low water syneresis ratio of the low-amylose rice, the firm gel of the high-amylose rice, and the low adhesiveness of the Sari-queen gel imply that the various newly developed rice cultivars can be used for many different kinds of cooking and processing.

CONCLUSION

Five newly developed rice cultivars (aromatic Sari-queen, low-amylose Dohoku 43, high-amylose Hoshiyutaka, giant-grain Ochikara, and high-yield Habataki) were studied. To determine the properties of the flour and starch of each of these newly developed cultivars, the swelling power and solubility, photopastegraphy, viscography and starch gel texture were examined. The stability during storage at a low temperature was determined by measuring the water syneresis ratio and the whiteness of the starch gel. The results for swelling power and solubility indicate that the swelling power of the rice starch samples at 90°C ranged from 17 to 26. Hoshiyutaka had the lowest, and Ochikara the highest values. Dohoku 43 (low amylose content) and Nipponbare were difficult to swell.

The light transmission rise onset temperatures by photopastegraphy of the rice starch samples increased from 58 to 64°C. Hoshiyutaka was gelatinized at a low temperature, while Nipponbare was gelatinized at a high temperature.

The viscogram indicated an increase in the onset temperature from 57.5 to 63.0°C. Hoshiyutaka had a low temperature, while Nipponbare had a high value, similar to the results obtained by photopastegraphy. Sari-queen showed a high maximum viscosity, a high viscosity in the cooling step and a large breakdown, i.e., low heat stability. Hoshiyutaka, which had a viscosity curve similar to that of the corn starch, can be used in foods by taking advantage of its gelling properties. Compared with the rice starch samples, the rice flour samples each showed a higher gelatinization temperature and lower viscosity by about 200 B.U.

Measurements of the starch gel texture indicate that Hoshiyutaka and Sari-queen had high firmness, this firmness being increased when stored at a low temperature. The Nipponbare gel was soft, and the Dohoku 43 gel was intermediate in softness. Stirring a hot paste of cooked starch during viscography while it cooled from 95 to 25°C generated a paste at 25°C rather than a gel. As a result, the firmness decreased while the adhesiveness increased. The Hoshiyutaka rice flour paste had high firmness and high adhesiveness, while the Sari-queen and Ochikara rice flour pastes only had high adhesiveness.

The freeze-thaw stability was determined on the basis of the amount of syneresis water. While Dohoku 43 had low water syneresis, Hoshiyutaka showed a high level of water syneresis with 1 cycle, indicating that this starch would be liable to undergo aging.

Determination of the whiteness indicates that, when stored at a low temperature, the Dohoku 43 gel had low whiteness and high transparency, while the Hoshiyutaka gel was cloudy and had high whiteness.

This third study enabled the gelatinization and retrogradation properties, gel texture and stability of the flour and starch of newly developed rice cultivars to be determined. Forthcoming studies will look at how the varied properties of the flour can be used for many kinds of cooking and processing, including couscous and traditional Japanese sweets and cakes (Dango and Uiro).

This study forms part of the project, "Development of New Paddy Field Crops Aiming at Enlargement of Demand," undertaken by the Japanese Ministry of Agriculture, Forestry and Fisheries. We express our
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grateful thanks to Kamikawa Agricultural Experiment Station, Hokuriku Agricultural Experiment Station, Chugoku Agricultural Experiment Station, and National Agriculture Research Center for providing us with the valuable rice samples.

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新形質米から得られた米粉および米澱粉の性質

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原稿受付平成 9 年 7 月 16 日；原稿受理平成 9 年 12 月 15 日

新形質米の米粉および澱粉の性質を知る目的で、バスタイプ型香り米のサリークイーン、低アミロース米の道北 43 号、多収米のオオチカラ、巨大粒米のハバタキ、インディカ系高アミロース米のホシユタカの 5 種を日本晴と比較した。混雑力・溶解度、フォトペーストグラフィー、ビスコグラフィー、ゲルのテクスチャーを求め、ゲルの離水率、ハンター白度の測定から低温貯蔵安定性を検討した。90℃における米粉粉の混雑力は 17-26 を示し、高アミロースのホシユタカが低く巨大粒のオオチカラは大であり低アミロースの道北 43 号・日本晴は膨潤しにくい、米粉粉の透光度上昇温度は 58-64℃を示し、ホシユタカは低く日本晴は高くなかった。添加物の影響では食塩・ショ糖が顕著であった。粘度測定から香り米のサリークイーンは粘度が高く、ホシユタカはコーンスターチに近似の曲線を描き、米粉粉還元力に比べて糊化温度が高い粘度は低い、澱粉ゲルはホシユタカ、香り米のサリークイーンは硬さがあり日本晴は軟らかく低アミロース米の道北 43 号はこれらの中间であった。ビスコグラフィーで冷却 25℃まで摂拌を繰返したゲルは、ゲル化が阻害され硬さが低下し粘着性が増大した。低アミロース米の道北 43 号は離水・白度が低く、ホシユタカは老化しやすく不透明なゲルであった。本報告で用いた新形質米各種は幅広い性質を示し、いろいろな調理や加工に利用できることが明らかとなったことから、今後は北アメリカ料理のクスクス、団子やういういのような伝統的な和菓子や蒸し菓子などの調製について検討を行う予定である。

キーワード：新形質米、混雑力・溶解度、凍結・解凍安定性、離水率、ハンター白度.